

USER SPECIFIC ASSISTIVE TECHNOLOGY: HAND MOUNTED SWTICH CONTROL PLATFORM DESIGN

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USER SPECIFIC ASSISTIVE TECHNOLOGY: HAND MOUNTED SWTICH CONTROL PLATFORM DESIGN

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	Three Dimensional
3DP	3D Printing
ABS	Acrylonitrile Butadiene Styrene
ALS	Amyotrophic Lateral Sclerosis
AM	Additive Manufacturing
AT	Assistive Technology
CAD	Computer Aided Design
CHOA	Children's Healthcare of Atlanta
Duke	Duke University
FDM	Fused Deposition Modeling
GH	Grasshopper
GSU	Georgia State University
HUI	Human UI
OT	Occupational Therapist
Rhino	Rhinoceros
RP	Rapid Prototyping
SLA	Stereolithography
SLS	Selective Laser Sintering
SMA	Spinal Muscular Atrophy
UI	User Interface
USAT	User specific assistive technology
USAT-HS	User specific assistive technology hand-mounted switch

SUMMARY

The purpose of this project is to design a platform for user specific assistive technology. This platform would allow occupational therapists to design and deliver highly customizable hand mounted switch controls for persons with severe disabilities using rapid prototyping tools. Specifically, occupational therapists would be able to adjust a pre-designed model through an intuitive user interface therefore change the design to meet users' unique needs.

The study first conducted literature review about assistive technology and rapid prototyping, then used participatory approach and human centered design methodology, engaged three occupational therapists to design and develop the platform through workshops and interviews. The aims of this project including designing the switch device, platform user interface and system packaging, and evaluating the designs with the occupational therapists. Findings, limitations and future work were discussed in the end.

CHAPTER 1. INTRODUCTION

The purpose of this project is to design a platform for user specific assistive technology (USAT). This platform would allow occupational therapists (OT) to design and deliver highly customizable hand mounted switch controls for persons with severe disabilities using rapid prototyping (RP) tools. Specifically, OTs would be able to adjust pre-designed models through an intuitive user interface (UI) therefore change the design to meet users' unique needs.

1.1 Problem Statement

Assistive Technologies (ATs) are crucial for people with disabilities to maintain good quality of daily life. People with different disabilities have various functional needs, and therefore requires user specific ATs which is highly customized to meet their unique needs. The lack of USATs will affect user's adoption of the prescribed device and treatment, thus hinder their rehabilitation. However, USATs are still not prevalent due to its high cost. The new RP technology with three-dimensional (3D) modeling and 3D printing (3DP) can provide low volume, rapid manufactured, highly customized products with relatively low cost and requirement of hardware. Such USATs without clinical evaluation have been distributed in online community for people to download and use, while the safety cannot be guaranteed for patients (Buehler et al., 2015). On the other hand, OTs are clinically trained to make ATs for patients, but they cannot take advantage of the 3DP technology due to the barrier of learning 3D computer aided design (CAD) modeling software. Although 3DP is very promising and has been applied in many medical fields, currently there is no such a system that allow OTs to operate the design of ATs efficiently.

In this project, we developed a USAT system, including (1) a pre-designed parameterized switch control model; (2) a simple-to-use CAD software interface that could enable novice user such as OTs, to change the design by adjusting a set of parameters, export the file ready for 3D printing; and (3) a system package that allow users to assemble all the components to complete the device design. During the process, we explored the co-design process for designers to work with OTs to create a system.

1.2 Project Significance

AT can maintain and improve an individual's function and independence, thereby promoting their quality of life. Specifically, it enables disabled people to live healthy, productive, independent, and dignified lives, and to participate in education, the labor market and civic life (World Health Organization, 2016). With AT, some patients could reduce the need for formal health and support services, long term care from caregivers; without AT, people are often excluded, isolated, and locked into poverty, thereby increasing the impact of disease and disability on a person, their family, and society (World Health Organization, 2016).

Globally, there are more than one billion people who need one or more ATs (World Health Organization). With an aging population and a rise in non-communicable diseases, it would increase to more than two billion by 2050, many of which need two or more ATs (World Health Organization, 2016). Despite the high demand for AT and its related services, it's still not accessible for those in need. Currently, only 1 in 10 people in need have access to assistive products due to “high costs and a lack of awareness, availability, trained personnel, policy, and financing” (World Health Organization, 2016). According

to the WHO report, the AT industry is limited and specialized, serving primarily high-income markets (2016).

While AT has the potential to improve people's lives, getting the appropriate AT is very hard. In some cases, commercial ATs are very expensive and not customizable to meet user's specific needs (Buehler et al., 2015). With those reasons, people start to design and create their own ATs using rapid prototyping tools (Buehler et al., 2015). Self-designed ATs are superior to off-the-shelf ATs in terms of availability or price; and due to user involvement, it can increase buy-in and reduce user abandonment. Some self-designed ATs can even achieve the same functionality with much lower price than their counterparts (Buehler et al., 2015). However, currently there is a large gap between clinical practice and the work of volunteer AT designers (people who design their own ATs but are not OTs) (M. Hofmann et al., 2016). According to M. Hofmann et al., clinicians produce safe and robust device but cannot leverage rapid prototyping in their practice, while designers or maker community could produce large quantity of unique and customized designs, but those designs are not validated; they suggest a new way to bridge the gap, i.e. allowing OTs to share their expertise to design communities and for designers to support OTs with a collaborative design process and more validated AT designs (M. Hofmann et al., 2016).

It is always attractive to design a platform for OTs to leverage the potential of 3D modeling and 3DP technologies for engineering affordable, highly customized ATs. As we know, healthcare as general is recognized as a domain that requires an approach closed to mass customization because of the large diversity of human body (Igoe T., 2011). Meanwhile, 3D print technology has been applied in many medical field, including allowing highly customized ATs with lower cost. However, it is difficult and time

consuming to iteratively design complex devices (M. K. Hofmann, 2015). This paper will utilize participatory design approach, engaging OTs to design and develop an AT co-design platform, that empowering OTs to leverage RP potentials to produce highly customized 3D printed ATs. With this platform, OTs could adjust critical 3D CAD parameters to modify an existing AT design through intuitive 3D CAD modeling UI.

1.3 Objective and Specific Aims

The objective of this project is to design a system that empower OTs to design and deliver user specific AT using RP tools. Particularly, for this project, the goal is to design and develop a USAT hand mounted switch control (USAT-HS) design system, to help OTs, who are normally novice users on 3D CAD modeling, to design a hand mounted switch control, by changing parameters of a parametric 3D model via intuitive UI. The USAT-HS system would also allow OTs to create a customized AT model with specific user's needs, export 3D print-ready file, assemble the parts together with instructions, and deliver the device to the end users, i.e. people with severe disabilities.

This project aims to first review existing literature for AT, OT, 3D modeling, 3DP, RP application in rehabilitation and AT area. Then, this project would use participatory design approach to engage three expert users (OTs, clinicians, or any AT related researchers) to refine the design objectives, design the system (including hand held switch control device design, 3D modeling and printing interface design, system packaging design). Finally, OTs would be involved to evaluate and refine the system design together with designer to improve its efficiency, usability and discuss about potential future work.

CHAPTER 2. LITERATURE REVIEW

2.1 Assistive Technology and Occupational Therapist

The Assistive Technology Act of 2004 defines an AT device as “any item, piece of equipment or product system acquired commercially off-the-shelf, modified or customized, used to increase, maintain, or improve functional capabilities of individuals with disabilities” (“Assistive Technology Act of 2004,” 2004). These devices are usually customized by physical therapist who can precisely determine the patients’ needs but don’t necessary know the methods to design and deliver effective AT for their patients (McDonald et al., 2016).

An AT service is defined as “any service that directly assists an individual with a disability in the selection, acquisition, and use of an AT device” (“Assistive Technology Act of 2004,”). In practice, AT service is provided to clients (patients) across the life span, across a spectrum of disabilities and in wide ranging medical as well as community-based settings. Leading disciplines that provides AT services include OTs, PTs, speech language pathologists, special educators, vocational rehabilitation counsellors, technology suppliers and other “AT specialists” (Sajay Arthanat, 2017). In this project, we are focusing on the co-design process of a AT design system with OTs.

OTs have a history of modifying and making AT to fit the unique needs of their patients (McDonald et al., 2016). However, lack of materials, time and access to training can restrict what they can create (McDonald et al., 2016). McDonald et al. also propose that 3DP is particularly useful for AT production because of its ability to localize

production and customize 3D models to user's exact specifications (2016). However, there are difficulties for OTs to leverage RP technologies to create ATs, because they don't have the skill set of using 3D CAD software to model 3D printable designs. According to Department of Commerce report on Technology Assessment of the U.S. Assistive Technology Industry, "Certified Rehabilitation Techs, Occupational Therapists with design/manufacturing skills" is reported as one of the AT Industry Skills Shortages (*Technology Assessment of the U.S. Assistive Technology Industry* 2003).

2.2 Assistive Technology for People with Weak Hands

There are several severe diseases that would cause people with impaired movement. Spinal muscular atrophy (SMA) is an autosomal recessive neuromuscular disease characterized by degeneration of alpha motor neurons in the spinal cord, resulting in progressive proximal muscle weakness and paralysis. Estimated incidence is 1 in 6,000 to 1 in 10,000 live births and carrier frequency of 1/40 - 1/60 (D'Amico, Mercuri, Tiziano, & Bertini, 2011). Amyotrophic lateral sclerosis (ALS), commonly known as Lou Gehrig's disease, is another progressive neuromuscular disease. When the motor neurons can no longer send impulses to the muscles, the muscles begin to waste away; and according to statistics from Johns Hopkins Medicine, this disease affects as many as 30,000 in the United States, with 5,000 new cases diagnosed each year (2017). According to the Muscular Dystrophy Association, in late stage of ALS, patient will have severely limited mobility, unable to care for own needs, unable to speak, and patient will need powered wheelchair, hospital bed, mechanical lift, switches that enable any moving body part to operate computers, environmental control units and communication devices, and will require 24-hour care from caregivers (2013). People with severe motor and intellectual

disabilities would need effective communication or alert system to fulfill their requests for daily activities. Due to their various health conditions, some verbal controllers are not applicable in their situations since they cannot speak very clearly (Saunders, Smagner, & Saunders, 2003).

2.3 Assistive Technology and RP Techniques

2.3.1 Parametric 3D CAD Modeling

For commonly used CAD modeling methods, the geometry is controlled by geometric features. While in a parametric model, the geometry is controlled mostly by non-geometric features, often identified as parameters, and can be defined by dimensional, geometric, or algebraic constraints (Shah, 1991). The benefit of parametric modeling technique is obvious: if properly used, parametric CAD enables the addition of design semantics to the model, which translates into the rapid alteration of existing models by simply editing the values of some parameters (Camba, Contero, & Company, 2016). According to Camba et al., the quality of a parametric CAD model is largely determined by the level of flexibility and adaptability of a 3D model (how easy it is to alter the geometry) as well as its reusability (the ability to use existing geometry in other contexts and applications) (2016).”

Although parametric modeling is a very effective way to model for reusability, it has limitations and challenges. Parametric CAD modeling is “a powerful method to model intelligent objects and their intended design behaviors...capturing and embedding tacit knowledge in parametric models requires a careful and well thought-out modeling plan because of the ambiguity and complexity of parametric modeling: there are many ways to

implement the modeling depending on design intent, and when multiple sets of object-behavior patterns are considered, the number and the complexity of parameters and geometric constraints grows exponentially (Lee, Sacks, & Eastman, 2006)”.

2.3.2 *Additive Manufacturing(AM) and 3DP*

AM, widely known as 3DP, is a technology that involves manufacturing a part by depositing material layer-by-layer (Conner et al., 2014). The first 3DP technology stereolithography (SLA) was invented partially to be used as a prototype to convey the design intent; but as 3DP technology advances, it could print high-resolution parts and with stronger and more durable materials. 3DP evolved beyond visual prototyping and started to include functional prototypes that can be used in fully function mechanism systems (Campbell et al., 2007). Since there is no need for tooling, rapid prototyping method is more cost effective, and take far less time than conventionally manufacturing method, to produce low volume, high level customized parts; while at the same time, it could provide the same functionality (Conner et al., 2014).

There are many other broadly used techniques other than SLA among industry and consumers (Gao et al., 2015)). According to Sculpteo’s 3rd annual report on 3DP and Digital Manufacturing, the top three 3DP technologies used by the industry from 62 different countries are (1) fused deposition modeling (FDM), (2) selective laser sintering (SLS), and (3) SLA (Sculpteo, 2017).

Gao et al. has summarized a timeline of significant developments and the resulting products for four groups of different 3DP solution: industrial grade, hobbyist/DIY grade, supportive community/commercial services, and 3D design/modeling software (Gao et al.,

2015). In the timeline, they present a list of worldwide supportive business communities and marketplaces for 3DP, including Shapeways from Netherlands, i.materialize from Belgium, Ponoko from New Zealand, Sculpteo from France, ZoonRP and RedEye from US; these business facilities allow designers to upload their designs, have them made and ship the finished product back (Gao et al., 2015).

2.3.3 3D Modeling Interface for Novice User

Although 3D printers became cheaper and more accessible, it is still difficult for novice user to create complex 3D models and leverage the potential of this technology. It requires elaborate training and practice for the user to learn the concept of creating 3D CAD models. Researcher are trying to help novice user to use 3D modeling software by developing various UI, without making the users going through the long CAD learning and training period. Those interface development research can be categorized into three fields: (1) natural user interface-driven shape modeling is trying to reduce the cognitive burden of the user, using sketch-based interfaces for modeling, gestured-based modeling (Kinect, Leap Motion, PrimeSense), and tangible-based shape modeling (using tangible and haptic devices for creating and modifying free-form 3D shapes); (2) 3D optical scanning to allow creating or modifying current existing shape; (3) co-design/co-creation platform: lower the barrier for user to get through the solid modeling process, providing the user an opportunity to influence the design of an artifact based on his/her specific needs (Gao et al., 2015). Co-design processes often use design toolkits to enhance creativity and facilitate the communication between different actions (Francesca, Valentina, Jelle, & Marinella, 2015).

2.3.4 Collaboration Design Platform

According to Gao et al, collaboration platform could take the form of a web-enabled software tool that will allow users to modify the dimensions of a pre-designed part using “sliding bars” to adjust design parameters (2015). They suggest that such platform (web based or application) would require a virtual environment and UI to interact with a parameterized model and an intelligent design tool to quickly validate each design iteration against a set of design constraints to evaluate performance (Gao et al., 2015). For example, a team from Loughborough University used Grasshopper (GH), a plugin for Rhino developed software “PenCAD” enables any user to easily develop geometric variations of a ballpoint pen (change dimensions, color and overall shape) (Ariadi, 2012). Besides modifying existing design, user can also modify an existing model with collaboration platform. For example, an application called “Uformit” software, is an online 3D model community that allow users to make modification to the 3D models that they uploaded (Gao et al., 2015).

Another co-design application, Reprise, was created by a group of researcher and computer scientists, for specifying, generating, customizing and fitting adaptations onto existing household objects (Chen et al., 2016). Reprise allows users to firstly express what type of action is applied to an object; secondly, based on that high-level specification, Reprise automatically generate adaptations of that object; thirdly, users can use “simple sliders” to customize the adaptations to better suite their needs (adjusting tightness for gripping, enhancing torque for rotation, change size of base for stability); finally, this design tool will provide the user with a toolkit of fastening methods and support structures, for fitting the adaptations onto existing objects (Chen et al., 2016). It’s a very versatile AT

design platform, however in the paper Chen et al. did not mention the involvement of OTs or end users for designing, development or using the Reprise software.

2.3.5 *Downloadable Assistive Technology Sharing Community*

Besides local maker communities that with 3DP capabilities (e.g. Fab Labs, Living Labs), there are also some online 3D modeling and printing communities. One of them called “*thingiverse.com*”, which is a downloadable assistive technologies sharing community (Francesca et al., 2015). It allows both end users, health professionals and makers to co-design assistive technologies online, and fabricated locally through commonly used 3D printer like MakerBot (Charbonneau, Sellen, & Veres, 2016). One good example of a project in this setting is “Enabling the Future” (enablingthefuture.org), where there is a network of passionate volunteers using 3DP to give the people that in need with a “helping hand”, with reference to 3D-printed hands and arms all over the world (Francesca et al., 2015). However, according to the survey about “the AT device designers on thingiverse.com and their motivation” has revealed that many of the designs are “created by the end-users themselves or on behalf of friends and loved ones”; and these designers frequently have “no formal training or expertise in the creation of AT” (Buehler et al., 2015).

With so many existing unique models uploaded by various designer and makers around the world, the customization feature on thingiverse.com, called “Customizer” provide people with specific needs about the model a very convenient way to modify it. In other words, the Customizer feature allows user to customize some of the existing models online, by simply changing a set of parameters. The only prerequisite for those

customizable models is that the source file needs to be created using OpenSCAD, which is a free software for creating 3D models using scripts. The difference between this software and other commonly used CAD software (for example, Solidworks) is that, OpenSCAD is not focusing on artistic aspects of 3D modeling, but the CAD aspect of it. This software has two main modeling techniques available: constructive solid geometry and 2D outline extrusion (OpenSCAD, 2018), which is good for simple CAD designs but might not adequate for complex parts modeling (“complex”, in terms of modeling technique).

2.3.6 3D Printing in Assistive Technology

There are many 3DP applications in the medical settings. Direct application includes creating prototypes for surgery planning or testing, implants, drug delivery and micro-scale medical devices, orthoses; and indirect applications including surgical aids and tools, mold for tissue engineering, etc. (Francesca et al., 2015; Giannatsis & Dedoussis, 2007; Miguel, Ana, & Andres, 2017). Lower cost of designing and manufacturing and highly customizable capability, make it easier to develop various medical products using 3DP technology. Because of this, more suitable personalized medical treatment can in a significant way influence therapy outcomes (Mikołajewska et al., 2014). Thanks to CAD, RP and computer aided manufacturing of physical models, traditional manual designing and manufacturing of personalized therapeutic solution can be changed. Patient-tailored therapy emphasizes necessity of individually shaped AT solutions becomes possible.

Mikolajewska et al. suggest five stages to customized AT for individual users using 3D modeling and printing technology (2014): (1) digital acquisition of the 3D geometric data directly from the patient or based on his/her pervious data file; (2) digital model is

stored on a computer; (3) rectification and modification/adaptation procedure without losing the original data; (4) creation of 3D model/final product based on 3D printer; (5) control of the 3D model (including patient comfort). They also suggest to carefully assess the material selection before applying the printed product in medical setting. Fernandez et al. compares two ways of making a custom-made static immobilization orthoses and provided a workflow for making the orthoses using 3D modeling and printing (Miguel et al., 2017). In the same paper, they also discussed about the printing method, material selection, and the labor work for removing printed support and manually completing surface finishing work (Miguel et al., 2017).

In the paper *3D Printing Assistive Device*, Stojmenski et al. have created an immobilizer, a hearing aid and hand helping device using 3D modeling and printing technology. Based on doctors' and patients' evaluation, they consider those printed parts are "more comfortable than standard casts and devices, far more accessible and affordable than off-the-shelf products" (Stojmenski, Chorbev, Joksimoski, & Stojmenski, 2015). Ostuzzi et al. used co-design process, involving OTs, end users, and designers to co-create and co-manufacture ATs using low-cost FDM printers (Francesca et al., 2015). They based on the importance of the end users' occupation and engagement in the design process of their own ATs and focused on the idea of developing a co-design and co-production process to create personalized ATs (Francesca et al., 2015). In that study, the designer created some reference product to help the other stakeholder to start with, and this process was developed by designers only and not actively involving with the end users and OTs; designers tried to imagine and address the users' needs by developing benchmarks, using their own personal experience and conducting online researches (Francesca et al., 2015).

McDonald et al. collaborated with OT professors and students at a medical university to integrate 3DP and AT design into a graduate-level physical therapy class, and they identified four considerations relevant to integrating 3DP into clinical practice: 1) exploring augmentations versus novel AT designs; 2) improvements to novice 3D modeling software, 3) adjusting for prototype fidelity, and 4) selecting 3DP materials (2016). Through this research, McDonald et al. also identified opportunities and barriers to 3DP in the field of physical therapy. Opportunities includes: (1) Low-tech DIY-AT experience: most OTs have low-tech DIY AT experience and this experience could easily transfer to design AT with 3D modeling tasks; (2) Medical expertise: OTs provides crucial medical expertise to evaluate the functionality of AT, as well as generate and implement ideas for improvements in AT design; (3) User access: OT treats patients with various conditions and have the capacity to reach a large number of users; 3DP technology and existing shared design repositories can address this diverse set of AT users, and expand OT knowledge in developing AT and related applications(McDonald et al., 2016). The clinical barriers to 3DP adoption might include: (1) Limited experience and time: OTs believes they don't have enough time to fully master the 3D modeling and printing technology and they just start to realize the potential of applying them in AT; (2) Ease of purchase: when standardized AT is easy to acquire and typically covered by insurance, while highly customized ATs can be costly and have lengthy insurance and billing processes, people tend to give up the latter if possible; (3) Standardized reliability: compared with reliable and rigorously tested device, OTs may be hesitant to prescribe novel products to their patients; (4) Liability of Do-It-Yourself-AT (DIY-AT): if a DIY-AT failed, OTs are becoming the manufacturers of their patient's device, and therefore accepting the liability

for that new device; also materials for 3D printed AT are unregulated and not tested for medical use (McDonald et al., 2016).

CHAPTER 3. DESIGN METHODOLOGY AND CONSTRAINED DESIGN OPTIONS

3.1 Design Methodology Overview

This study utilized participatory design approach and human centered design methodology, to actively engage three OTs (including healthcare professionals works in AT field) from Children's Healthcare of Atlanta (CHOA), Georgia State University (GSU) and Duke University (Duke) to facilitate the design of the USAT-HS platform. The three roles involved in this system are as follows

- (1) OT: people who have formal clinical training about how to provide AT services and create AT devices. Most are novice user for 3D modeling and 3DP technologies.
- (2) Designer: people who have formal training of design, could use RP technologies to create solid design and prototypes.
- (3) End user: people with severe disabilities, and need a hand-mounted switch control AT to improve his/her well-beings and/or assist their daily activities.

In this participatory design process, end users' perspectives were replaced by the experience provided by OTs working with end users to offer AT design information. OTs were not the subjects but platform users and design partners throughout this project.

There were four design phases of USAT-HS system:

- (1) Pre-defined system
- (2) Device design (evaluation and Re-design)
- (3) UI and interaction design (evaluation and Re-design)
- (4) System package design (evaluation and Re-design)

3.2 Prototyping Tools and Software

3.2.1 Device Design

SolidWorks was selected as the prototyping software for modeling the switch control device; Rhinoceros 3D 5.0 (Rhino), GH (Rhino plugin) were selected as development software. Two types of 3D printer were used in this study.

(1) Stratasys Dimension 1200 (with soluble support material and ABS)

Literature review indicates that FDM 3DP technology and ABS materials are widely used and accessible for both industrial grade and consumer grade 3D printers (Francesca et al., 2015; Miguel et al., 2017). We decided to use soluble support material, since it do not require the post process of manually removing support materials for the 3D printed parts. This support material allows more complex parts to be printed, including overhanging features or features with many details.

(2) EOS Omega (with Nylon)

For this project, we also used EOS printer with nylon powder to print out some prototypes for comparison. This solution provides very durable, flexible print without supporting material. However, this technique is only available for industrial grade printers, therefore is not as accessible as other consumer grade 3D printers and is more expensive.

3.2.2 Interface Design

This study utilized prototyping software Sketch to assist the design of the system UI, and Rhino 5.0, GH, Human UI (GH plugin) as development tools.

We selected Rhino as the main CAD modeling software due to its powerful plugin capabilities. GH, as a widely-used plugin for Rhino, allows user to create relative complex parametric models without programing or scripting. HUI is created for GH as another powerful Rhino plugin that enables user to generate professional looking GH apps with custom UI, without writing any code. We also briefly explored other prototyping methods, including: (1) using scripting features directly from those popular 3D CAD software (SolidWorks, Rhino, Fusion 360); (2) using OpenSCAD, a web-based CAD application (scripting-only); and (3) coding from the scratch. For this study, Rhino Grasshopper and HUI are a good combination that allows designers to complete the project efficiently.

3.3 Pre-defined USAT Hand Mounted Switch Control Design

During the early development stage of this project, clinicians were engaged and the concept of “an easy-to-operate hand mounted switch control” became a design opportunity. There were several pre-defined design options. The design objective was to design a system that allow OTs to design a hand mounted switch control for their clients, with parametric input and intuitive CAD UI; print the design using RP tools, i.e. 3D printers; assemble the switch control with other commercially available parts; then deliver it to the clients. The initial USAT-HS design decisions to be offered to the OTs are listed in Table 1.

Table 1 Design Decisions to be Offered to OTs

Activation mechanism	<ul style="list-style-type: none"> - Single finger - Multiple finger - Wrist flexion/extension
Integrated components	<ul style="list-style-type: none"> - Switch: momentary or latched switch - Switch type:

	push button micro switch flex or bend switch
Human-device interface carrying structure for switches	<ul style="list-style-type: none"> - Universal cuff - Palmar splint - Finger splint - Tube or cylindrical mount
Connector	<ul style="list-style-type: none"> - Male or female 1/8" mono plug - Pig-tailed or jack integrated into hand interface

3.3.1 Concept Framework

An operational approach for design and fabrication of the USAT-HS was proposed as below. The system concept framework was also provided as shown in Figure 1.

- (1) Clinician identifies clinical needs
- (2) Anatomical measurements: linear measurements to proper size and configure hand interface
- (3) Device design
 - Computer application designed to lead clinician through design process
 - Selecting activation site/motion: single vs multiple fingers
 - Selecting a switch(s) to be integrated into the hand interface via menu driven interface
 - Selecting hand interface: choose between resting, palmar splint and cylindrical handle
 - Input measurements
- (4) Rendering of final design for approval
- (5) Select material

- (6) Send to printer for fabrication
- (7) Insert components (usually are commercial products that could be bought at local stores)

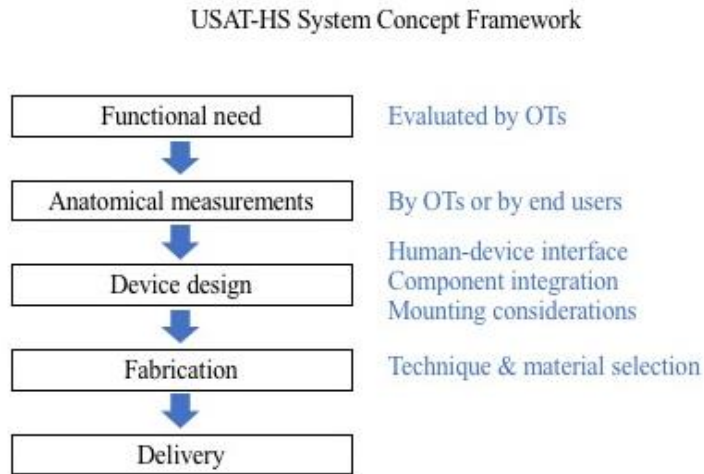


Figure 1 USAT- HS system concept framework

3.3.2 Participants and End Users







The primary user of this platform are OTs. For this project, we have engaged three OTs as co-design partners: one OT from GSU, one OT from CHOA, and one clinician working on ATs at Duke. Two of them have no experience of 3D modeling or printing, and one has limited experience in 3D modeling and 3DP.




End users (or what clinician called “clients”) of the USAT hand mounted switch controls would be people with little motor skills (very weak hands), and need customized hand mounted switch controls as AT to perform daily activities. Those end users might be people with ALS, or MLA.

After discussion with OTs, we identified several major uses of this user specific hand mounted switch control (as shown in Table 2): allow user to connect the switch

control to communication device, tablet (iPad), desktop, call bell/button. Those applications will dramatically increase the patient's independence and quality of life.

Table 2 Potential applications for the USAT-HS device

Application categories	Connection/ extra part needed	Examples	
Alert system/ Call button	Mono plug	Responsible personal alert system	
			
Computer or Tablet devices	Switch interface	Desktop/ iPad	
			
			
Communication devices	Mono plug	Nova Chat	Recorder-talker (talk switch module)

			
Toys (switch adapted toys)	Mono plug	Baby Einstein Musical Switch Adapted Toy	
			

3.3.3 System Design Criteria

Primary criteria:

- (1) hand-device interface fit end user's hand and provide enough support
- (2) low force (below 50g) to actuate the switch
- (3) people with severer disabilities should be able to actuate the switch easily
- (4) safe to use for the end user
- (5) easy for OTs to assemble the switch control device
- (6) easy for novice user of 3D CAD modeling and 3DP technology to design the device via UI

Secondary criteria:

- (1) the switch control should be lightweight
- (2) the switch control should be easy to clean and kept clean

(3) the device should be durable

Tertiary criteria:

(1) no soldering requires during the assembling process of the device

(2) the parts could be 3D printed at most commercial 3DP vendors or makerspace

CHAPTER 4. USAT-HS SYSTEM DESIGN AND DEVELOPMENT

4.1 Human-device Interface Design

4.1.1 Design Process

For this phase of the design, we followed the double diamond design approach (Council, 2018). Starting with discover phase, we benchmarked some of the current existing commercial switches for disabled people. During the define phase, we refined the design objective with the OTs. For the phase of design, we first created the concept reference design, then conducted concept design workshop with OT-EB and sent out design concept reference for OT-SC and OT-KC for additional design inputs. During the last phase delivery, we finalized the human-device interface design based on OTs feedbacks and assembled all components together.

4.1.2 Discover

After benchmarking for current existing switches for disabled people (see Figure 2 below), we found that most products are not designed for mounting with specific user's hand, instead just a single switch that can be activated by pressing the button. There's little room for custom fitting. Moreover, for most momentary switch, it requires more than 50g to activate. There is an opportunity to design a customized human-device interface to mount the switch onto user's hand, and let the user activate the switch with little force.

Good fit
hand mounted

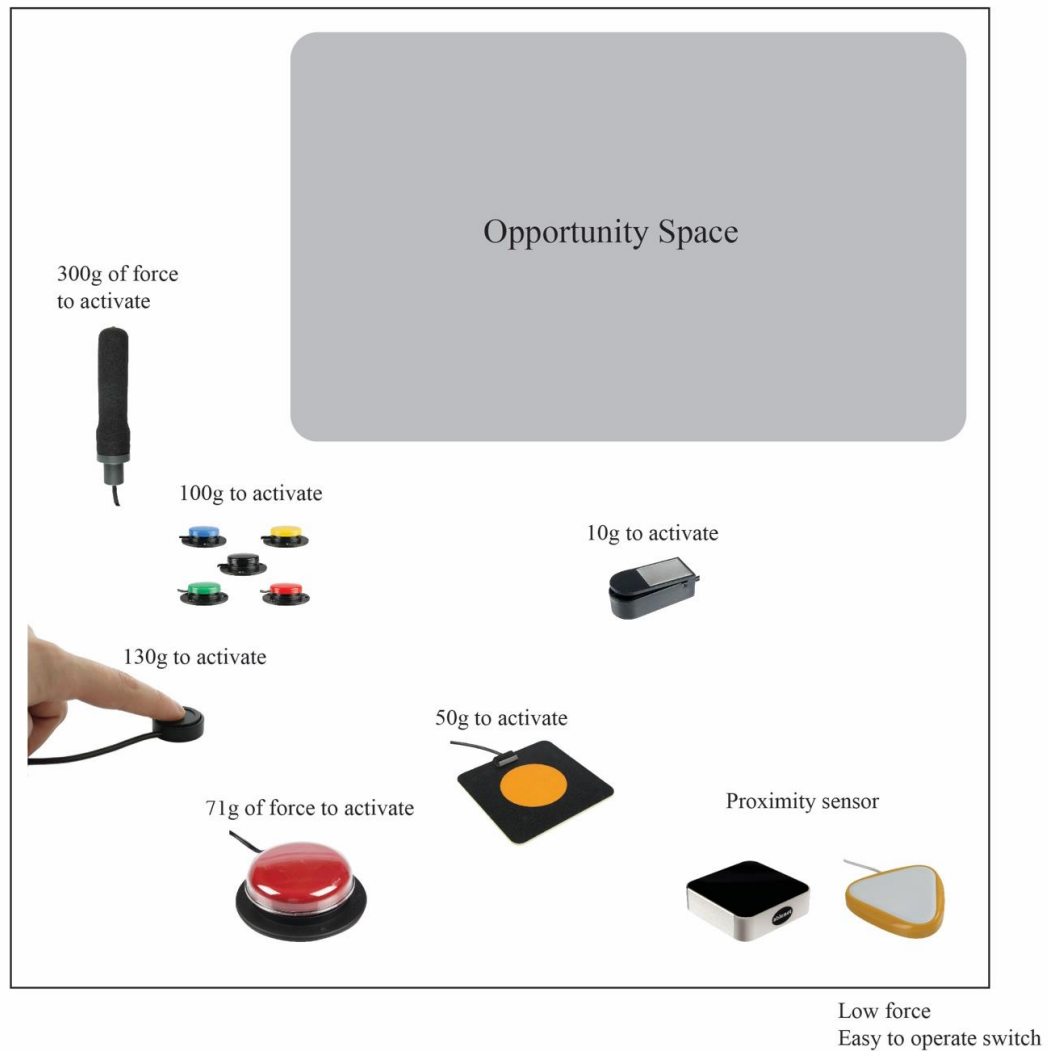


Figure 2 Benchmarking for current existing switch for people with disabilities

4.1.3 Define and Design

4.1.3.1 Human-device Interface Design Objective

- (1) Easy to scale to sizes
- (2) Easy to operate the low force switch
- (3) Easy to mount people's hand
- (4) Safe to use

- (5) Easy to assemble
- (6) Durable for everyday use
- (7) Clean and easy to keep clean
- (8) Lightweight
- (9) Easy to model

During the design stage, we identified some of the low force switch, no soldering needed connectors (or method to connect switch to mono plug wires), mono plug with lead wires, and cushion straps that are available to purchase. The part lists were finalized along with the device design.

4.1.3.2 Initial Concept Design

Before engaging with the OTs, we explored the potential designs of the human-device interface based on the research of computer mouse, a similar commercial product. Based on previous research and feedbacks from clinicians, the design was starting with a simple ellipsoid shape with a switch underneath the shell (see Figure 3 below for the initial concepts).

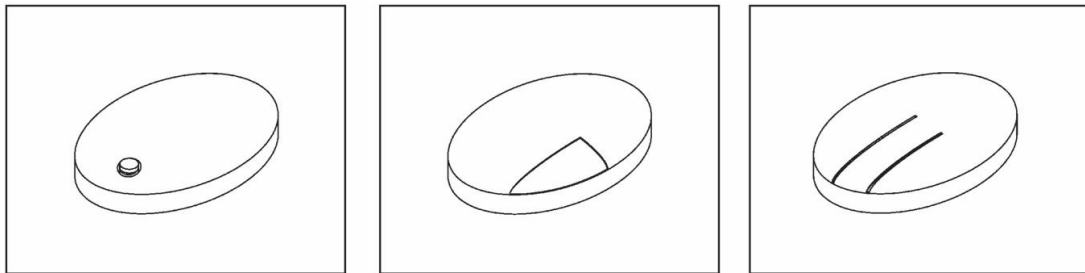


Figure 3 Initial concept design. From left to right are: Concept 1, 2 and 3

Concept 1 - with a cut out on the shell interface, user presses the switch cap to actuate the switch. Although it requires less complex model and mechanism design of the human-

device interface, the switch mounting and positioning is challenging. It requires high accuracy to place the switch and its cap under patient's moving finger(s).

Concept 2 - make a switch cap as contacting piece and fit that in the mounting surface. The benefit of this design is that there's less constraint for the type of switch to be under the contacting piece, and user can apply force on a bigger area to actuate the switch. However, it also increases the model complexity and requires more moving parts into the system.

Concept 3 - use living hinge as the activate piece. This design is simpler and has less moving parts than concept 2. The user can actuate the switch on a bigger area with less requirement of precision for the switch mounting location and control of the finger movement from the user.

After evaluating the three directions based on the criteria we identified earlier, we decided that concept 3 is more promising since it is simpler, and requires less movement precision from the user and less force to actuate the switch, which is attributed to its leverage mechanism. The living hinge structure will also reduce moving pieces in the design, making the model easier to develop from a technical perspective.

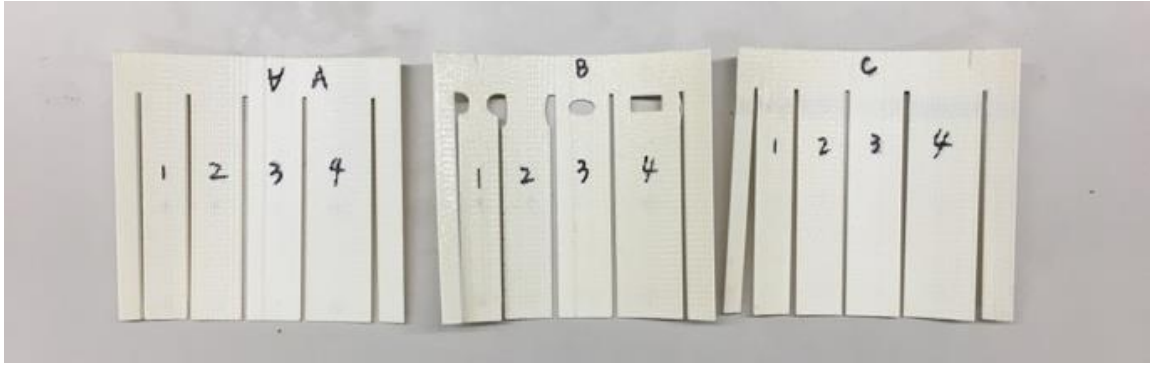


Figure 4 Living hinge design iterations

As shown above in Figure 4, we did a series of design iteration and evaluation on the living hinge mechanism design. As shown in Figure 5, we used weights and ruler to test the force that need to bend the 3D printed parts at two locations (on the edge and in the middle of the living hinge). Living hinge with various layer thickness, width and necking pattern were included in the design iteration. We found that the thickness of the living hinge part dramatically affects the flexibility of the hinge, while the thinner parts are easier to be deformed, and those with necking design patterns are slightly better than those without necking design patterns.



Figure 5 Test living hinge part with weights and ruler

4.1.3.3 Reference Design and OT Engagement

We created several concepts with renderings, 3D printed models and pink foam scale model (as shown in Figure 6). The design objectives and concept renderings were sent to the three OTs for initial device design feedback (see APPENDIX A. INITIAL DESIGN RENDERINGS). We also conducted an initial concept design workshop with OT-EB at GSU. She was presented with renderings, 3D printed prototypes, switches, straps and pink foam models as tool kit and design reference to start the switch control device design.



Figure 6 Initial design concept models

The goal for the workshop was to provide them with a design tool kit, and let them offer clinical support to the design process. Some key design questions were raised during

the workshop about: (1) living hinge mechanism; (2) strap location; (3) switch actuation force direction; (4) finger divisions; (5) wrist support; (6) material; (7) other suggestions.

OT-EB provided her clinical opinions about the design. She suggested that the movement limitation of patient's finger should be considered in the living hinge mechanism. Secondly, OT should be allowed to customize strap locations since patients have various conditions that might need different treatment. Otherwise, it would be hard for patient to actuate the switch from the side using thumb. Thirdly, the five-finger divisions on the design is not necessary for the majority of people whose thumb, index and middle finger are the fingers that perform most of the functionality and are stronger. Wrist support are also not necessary for similar reason. Fourthly, Material needs to be smooth and not causing harm to the patients, since most of the patients have sensation issues and won't notice the injury causing by the device with hard surface. Finally, OT should be allowed to add foam or cushion to further customized the design with comfort for their patients.

During this participatory design process, the designer took the lead by providing reference design for the clinicians, and the clinicians will provide feedback and design suggestions by describing the design details and providing reference design images through online searching. The designer could confirm the design feedback and suggestions by sketching out clinicians' idea and presented the concept at the workshop. Based on the feedbacks collected from the OTs, we further iterated the design and repeated the "design-feedback-revised design-feedback" mode. The progression of the device design is listed below (see Figure 7).

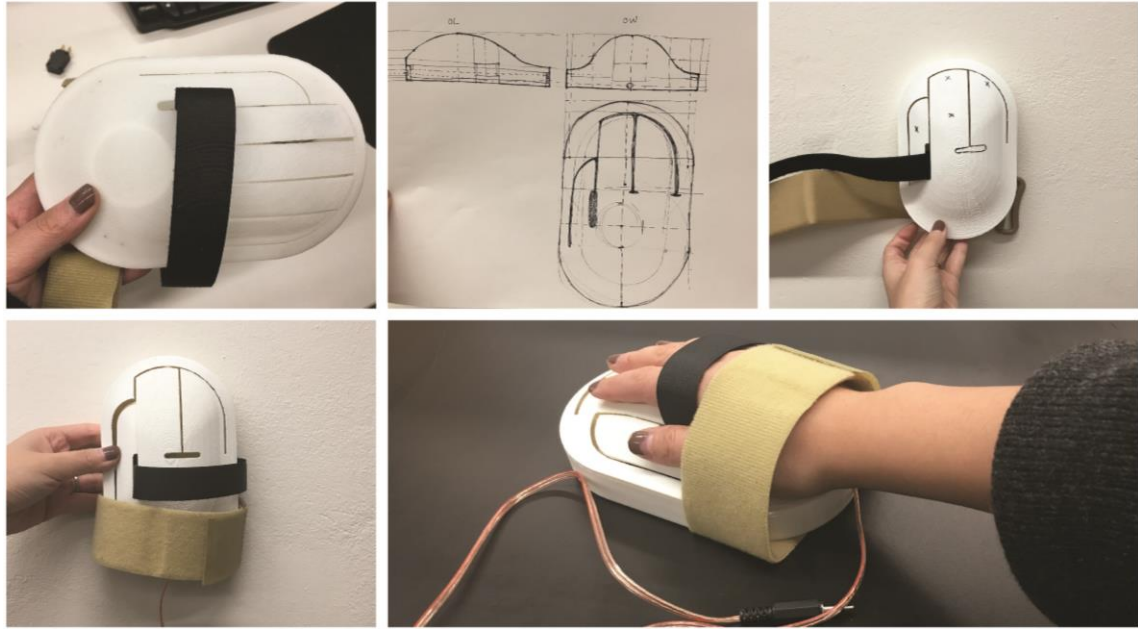


Figure 7 Device design progression (3D printed models and design sketch)

4.1.4 Deliver

Final design (see Figure 8) of the device has an adjustable curved upper surface to better support people's hand. Three living hinge plates were designed to support thumb, index and middle finger, ring and pinky finger. Strap slot was offered to secure the hand from the palm area while leaving enough movement room for the thumb. Necking feature was added to making the hinge easier to press down. Switch mounting wall were added so user can easily snap in the switch. Based on the weight testing results on the prototypes, the force required to activate the switches ranges from 15~45g.



Figure 8 3D printed final design with different sizes and switch selection, assembled with strap and mono plug

Parameters that OTs can change with this design:

- (1) hand length: change the length of the device
- (2) hand breadth: change the width of the device
- (3) curvature: change the fitting of user's palm to the device
- (4) strap slot width: use different width of strap for various end users
- (5) switch selection: choose which finger to actuate the switch, at force level from medium to light

The 3D printed prototypes were modeled using SolidWorks, printed with FDM method using ABS material with soluble support. Prototypes were also printed using EOS Omega printer with Nylon, to compare the material characteristics. Nylon parts were more durable and with better flexibility, but also more expensive.

After evaluating the design with OTs with photos and videos, we started to design and develop the 3D CAD parametric models of the design using Rhino and GH. Some minus modifications of the model were made to increase the effectiveness of the model and reduce the modeling complexity. As shown in Figure 9, a parametric relationship map was created to assist the modeling planning. This map present the relationship between the features of the model and internal /external parameters of the model.

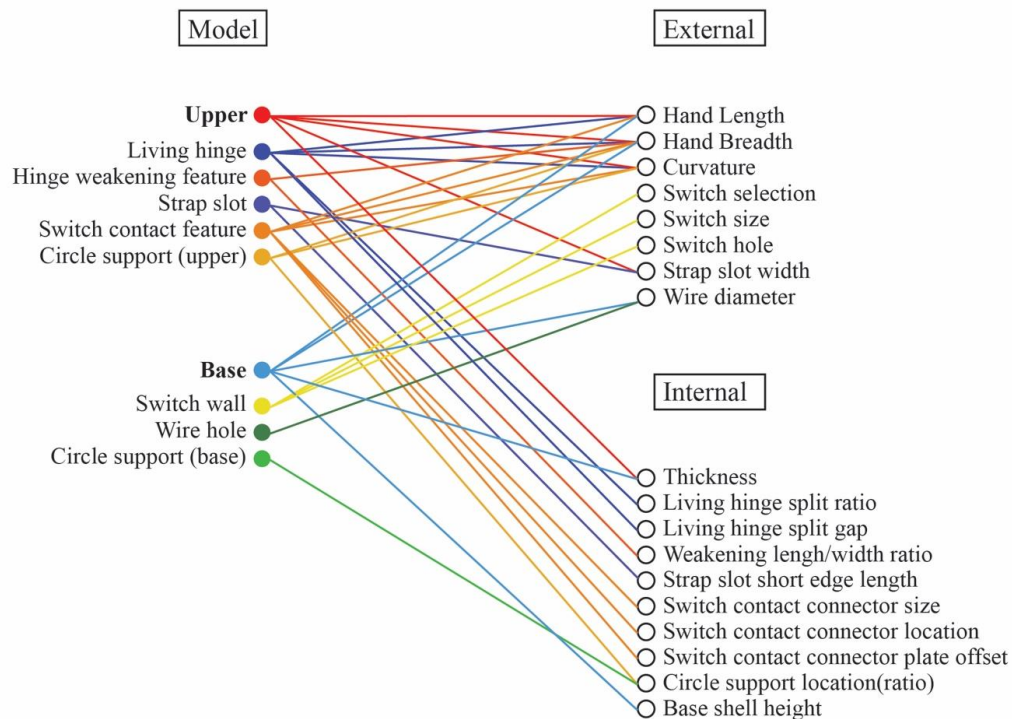


Figure 9 Parametric association map for USAT-HS device modeling

4.2 User Interface Design

After finalized the major parameters for the human-device interface design, the next step is to design and develop the interface of the USAT-HS system. During this process, we used human-centered design and participatory design approach, and conducted a series of workshops and interviews to facilitate the co-design process of the system with the three OTs.

For this study, we explored different parametric modeling tools and their build-in scripting capability, trying to identify the most cost effective (for both model and UI) prototyping tool to develop the platform. Rhino was finally chosen along with GH and HUI plugins to develop the model and system UI.

Among the three OT participants in this study, two of them has no experience working with 3D CAD modeling or printing experience. One of them has limited experience in working with modeling and printing.

With the parametric model developed, the major parameters/design inputs that determines the model outcome were also finalized.

They are listed as:

- (1) Hand Length
- (2) Hand Breath
- (3) Curvature
- (4) Strap Slot Width
- (5) Switch Selection
- (6) 3D Preview of the model

(7) Save and Export the STL file of the model

Paper prototype was created first to inform the design with basic elements and layout.



Figure 10 USAT-HS UI version 1 created with GH

After explored the essential HUI design techniques with GH using online tutorials, we used Rhino's GH and HUI plugins to create the UI (version 1) (see Figure 10) as a

reference design to help facilitate the participatory UI design process with OTs. This version was tested by two OTs. OT-EB could use the interface prototype at the REAR Lab at Georgia Tech (as shown in Figure 11), while OT- KC tried this interface prototype remotely via web-meeting application (as shown in Figure 12). They were asked to first have a device design in mind, and then go through the UI prototype, from opening Rhino and find the GH application file, design a human-device interface by changing some parameters, to finally export the STL files ready for 3DP. During this testing process, there's no extra instructions except a user manual for the UI (see APPENDIX B. WORKSHOP USER MANUAL). They were encouraged to think out loud and ask questions, because this will help the designer understand how the OTs were thinking and reacting to the UI design. At the same testing meeting, OTs were asked about (1) what is good about the design; (2) what need to be improved; (3) how they want to design the UI. They were also shown another three UI design for additional feedbacks (see APPENDIX B. WORKSHOP USER MANUAL for extra UI layouts). Those layouts alternatives emphasizing on different UI elements for the application, are low-fidelity wireframes, aiming to better facilitate the UI layout design with OTs.

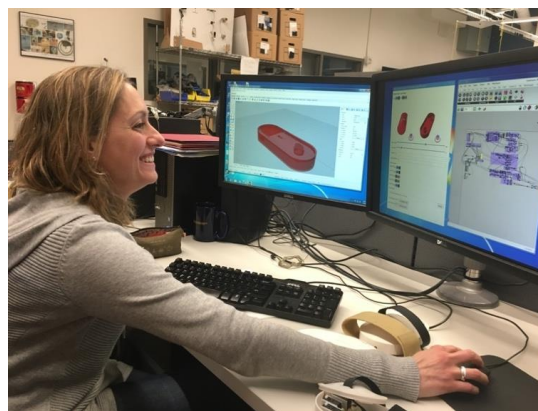


Figure 11 Test UI version 1 with OT-EB at REAR Lab

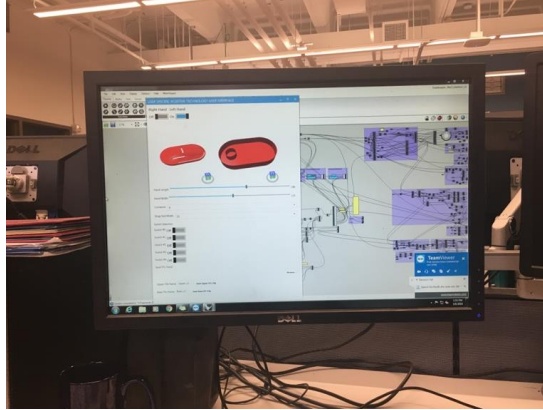


Figure 12 Remote test UI version 1 with OT-KC

After gaining enough design input from OTs, we utilized Sketch, a very popular UI design and prototyping application to design the wire frame and medium fidelity prototype based on their feedback. Major changes include creating the “3D model rendering preview” element as a separately opened window, instead of locating on the main screen; add detailed instructions about hand measurement; add curvature explanation on the screen; add switch selection explanation to guide the process. Two concepts, “Concept A” (as shown in Figure 13) and “Concept B” (as shown in Figure 14) were generated after this co-design process. Particularly, “Concept A” has one main parameter changing screen and a set of click-to-open sub-screens providing detailed explanations for each parameter. “Concept B” integrated the parameter screen along with all the detailed explanation sub-screens into one screen. The only separate window is the “3D model rendering preview”, since it’s not primarily required to complete the design process (user can always check the model in the Rhino window if preferred, or they can check the exported STL file in CAD software). These two concepts were sent to the OTs to gain further design inputs.

Concept A

Main user interface

User Specific Assistive Technology

1. Left hand

Right hand

2. Hand maximum length(mm)

How to measure

3. Hand maximum breadth(mm)

How to measure

4. Device curvature(mm)

What does it mean

5. Strap width(mm)

What does it mean

6. Switch selection

See switch location map

Thumb

Index/Middle soft

Index/Middle medium

Ring/Pinky soft

Ring/Pinky medium

Preview 3D model

7. Save STL file for 3D print

File path

Browse

File name(upper)

Save

File name(base)

Save

Click-to-open user interface for some detailed instruction/information

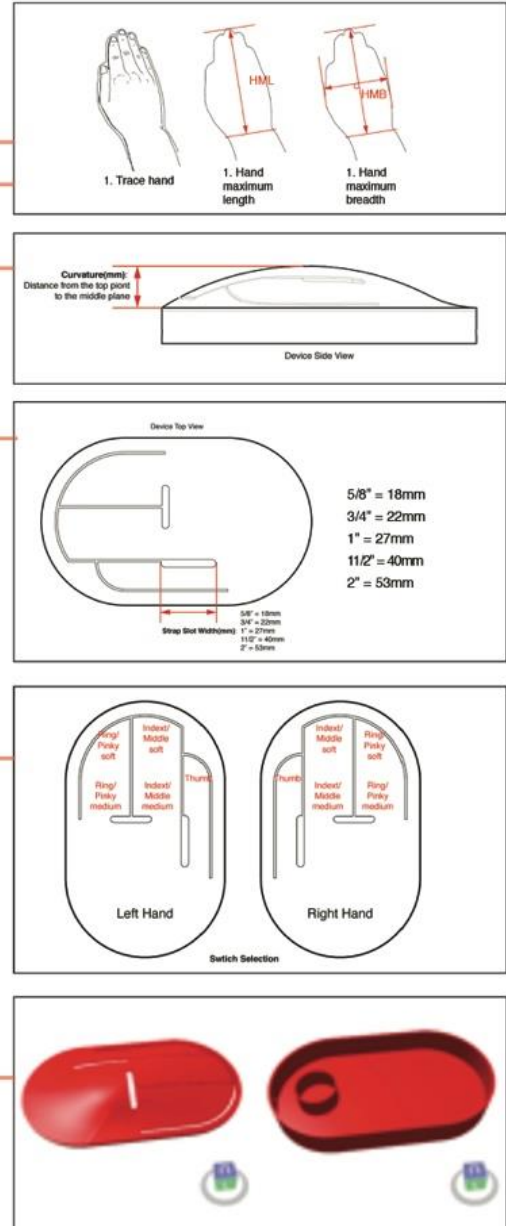


Figure 13 UI design "Concept A" medium fidelity prototype

Concept B

Main user interface

User Specific Assistive Technology

1. Left hand

Right hand

2. Hand maximum length(mm)

3. Hand maximum breadth(mm)

4. Device curvature(mm)

5. Strap width(mm)

6. Switch selection

Thumb

Index/Middle soft

Index/Middle medium

Ring/Pinky soft

Ring/Pinky medium

1. Trace hand

1. Hand maximum length

1. Hand maximum breadth

Curvature(mm): Distance from the top point to the middle plane

Device Side View

Device Top View

5/8" = 18mm
3/4" = 22mm
1" = 27mm
1 1/2" = 40mm
2" = 53mm

Left Hand

Right Hand

Switch Selection

Preview 3D model

7. Save STL file for 3D print

File path

Browse

File name(upper)

Save

File name(base)

Save

Click-to-open user interface

for some detailed instruction/information



Figure 14 UI design “Concept B” medium fidelity prototype

After evaluating the “Concept A” and “Concept B” separately, OT-EB and OT-KC strongly agreed with adding detailed explanation about each parameter, because it’s very handy to for them to modify design. They also both agreed that “Concept B” was better in terms of usability. Since “Concept B” has all parameter explanation available on the main screen, there’s no extra click to open any sub-screen for detail instructions, which enables OTs to quickly grasp all major information from one screen. They were positive about the “3D model preview” moved from the top to the bottom of the screen, and presented as a “click-to-open” feature rather than stick on the main screen, since for them the model checking is not the most important feature and could be substituted by looking at the Rhino live window or check the model after exporting from the application.

Based on all the design input from OT-EB and OT-KC, we created UI-V2 (as shown in Figure 15) with Rhino GH and HUI. Then we tested it on laptop (which is connected remotely with the desktop at REAR Lab at Georgia Tech) with OT-SC at CHOA (as shown in Figure 16).

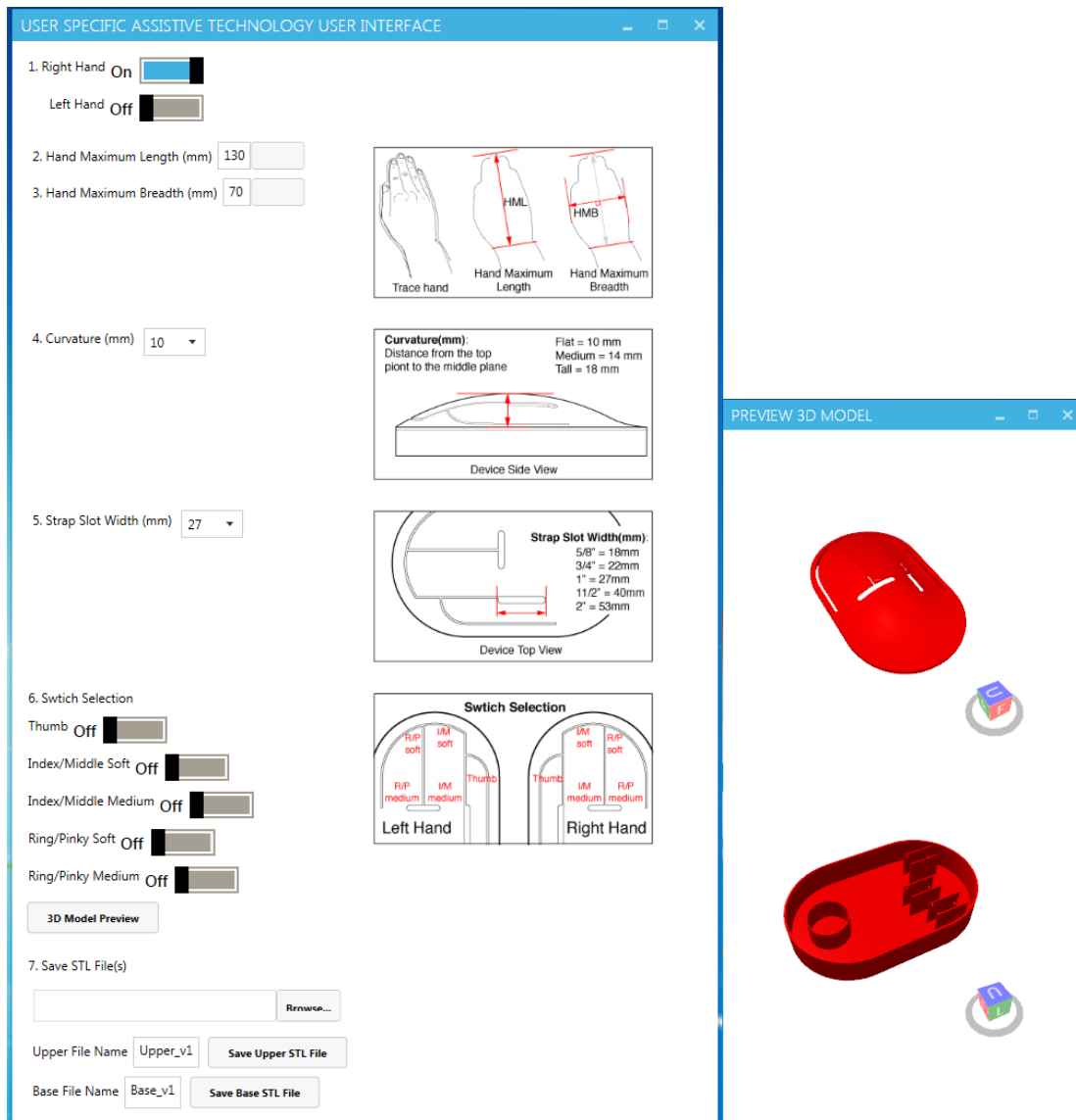


Figure 15 USAT-HS UI version 2 created with GH

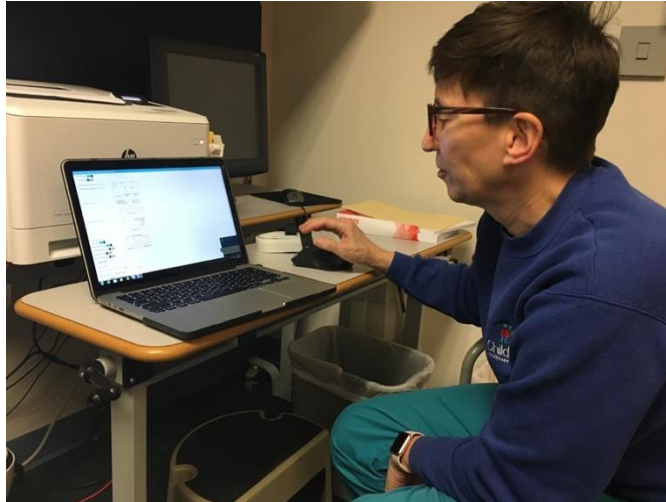


Figure 16 OT-SC tried the UI version 2 at CHOA

OT-SC was introduced about the device design and was asked to measure her own hand for the parameters that needed to create the hand mounted switch control. She then designed her own device using the interface created by GH and HUI, and exported her design as STL files. During this process, she was asked to think out loud and ask questions about the design, to help the designer understand what's her feeling and reaction about the UI design.

As a very experienced OT at CHOA, she provided many good suggestions about the wording of each design parameter's label, and anthropometric measurement terms. At last, we printed her design using the STL files generated by the USAT-HS platform at Georgia Tech.

Based on OT-SC's design input we modified the UI design for USAT-HS system in GH and HUI. The major changes were: (1) emphasizing on the measurement of the hand using yellow highlight and red texts; (2) replacing hand measurements (hand length and hand breadth) from sliders to number input with a save button (save button is the HUI

default design); (3) grouping switch selection design inputs, so it reads group one(thumb), group two (index and middle), group three (ring and pinky).

USER SPECIFIC ASSISTIVE TECHNOLOGY USER INTERFACE

1. Right Hand ☐ Off ☐ Left Hand ☒ On

Click on the blank button to confirm your entry.
Please make sure you are measuring the hand in resting position with fingers closed.

2. Hand Maximum Length (mm)

3. Hand Maximum Breadth (mm)

4. Select Curvature(mm)

5. Strap Slot Width (mm)

6. Switch Selection(Up to 3 switches)

Thumb ☒ On ☐ Off

Index/Middle ☒ Soft ☐ Medium ☐ Off

Ring/Pinky ☐ Soft ☐ Medium ☒ On

Click on this button to preview the 3D Model

7. Save STL File(s)

Upper File Name

Base File Name

PREVIEW 3D MODEL

Figure 17 USAT-HS UI version 3 created with GH

We conducted another two workshops for the system UI design for the other two OTs separately. During the work shop, USAT-HS UI-V3 (as shown in Figure 17) was tested with OT-EB and OT-KC remotely using their own desktops with online meeting connection to the desktop at REAR Lab at Georgia Tech. Then they were asked to think

out loud when they are entering their own design parameters (they measured their hand data prior to the workshop) using the system, and to ask questions freely. At last, they were asked about their feedback about the revised design and what their design suggestions.

OT-EB had minor problems using the UI to design her own device. She was confused about the confirmation button next to the text box and missed to click on it to save the entry for “hand length” and “hand breadth”. She found the UI are “intuitive to follow” but “open the file using GH was harder than I thought”. She also suggested to rewording the hand measurement instructions so OT can get the data correctly. The last design suggestion she provided was making sure the user knows how many switch they can select for each design.

During this workshop, KC missed the first section for selecting “left hand” or “right hand”. He suggested moving the measurement note, which are in red text and yellow highlight up to the top, so user can perceive the whole interface with the order of number 1-7 for all the design options. He also misunderstood the default text “175” in the text box for “Hand Length” and “110” for “Hand Breadth” as “maximum hand length user can enter is 175” and “maximum hand breadth user can enter is 110”. He suggested to rewording the label for the text box to reduce the confusion. After he entered the correct measurement for those two, he forgot to confirm the entry by clicking the blank button. “Adding some text or notice will help solve the problem” OT-KC recommended, “and it’s also helpful to add more feedback to confirm that the user has entered the input that are needed to complete the design”.

Based on all the feedback and design suggestions from the OTs, we revised the UI design (see final UI design as shown in Figure 18).

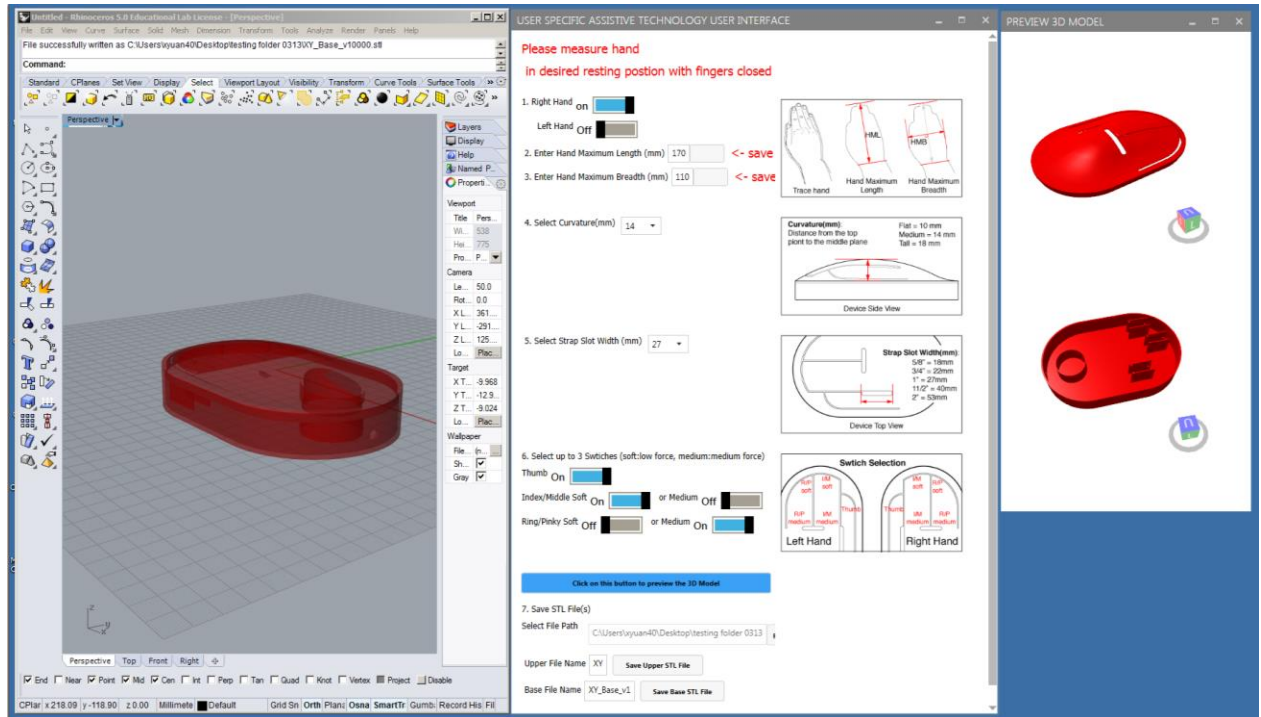


Figure 18 Final UI design, left: Rhino screen; middle: USAT-HS platform main screen; right: extra screen for 3D model preview.

The parts designed by OT-EB and OT-KC were printed in Georgia Tech. With the exported STL files, OT-KC decided to try to print on his FDM printer using ABS with ABS supporting materials. He encountered some printing issues with the file, since he didn't use the recommended printing methods (FDM with soluble support materials or SLA with Nylon).

4.3 System Package Design

During this process, reference user assembly manual was created. Then those documents were used as reference to facilitate the participatory design workshop with OTs.

Two OTs (OT-EB and OT- SC) were actively engaged in the co-design workshop and OT-KC evaluated the system package remotely via emails. The overall system package design was revised based on the feedbacks and design input generated from the co-design workshop.

After completing the design for the human-device interface hardware and UI design, the next step would be creating a system package that grouping all the elements into a whole system. The system package design includes the following items: user assembly manual, purchased parts list, hand measurement instruction and 3DP instruction. An assembly manual will help OT to put all components together with the 3D printed parts and therefor complete the device design. A list of all required parts could reduce the time for OT to search for qualified parts. 3DP instructions would offer the OT with clear instructions about how to ensure the best results of the 3DP process and compare different options.

Before the workshop, we created the package for each OT to complete the hand mounted switch control assembly. The assembly package (see APPENDIX C. SYSTEM PACKAGE DESIGN V1 for version 1) consists of: (1) a set of 3D printed hand-interface interface (upper and base parts) that designed by the OT from last UI design workshop; (2) micro switch(s); (3) sets of wires and connectors for the switch(s); (4) one male 1/8" mono plug (bring one just for the workshop, their design might need more than one); (5) straps; (6) hand measurement instruction; (7) assembly instruction; (8) part purchase lists. Below shown the actual setup for the system package design workshop with OT-EB (as shown in Figure 19).

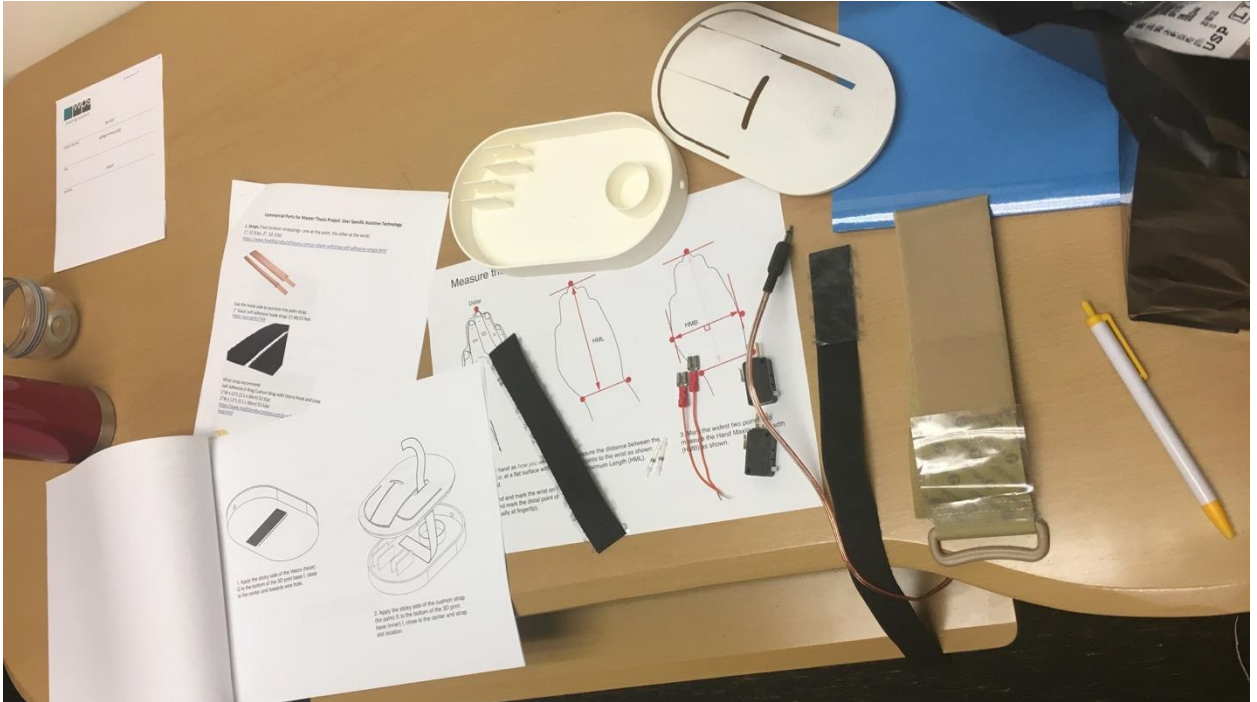


Figure 19 Workshop setup with parts to assemble the hand mounted switch control and related documents at GSU

During the workshop, the OT was first asked to briefly review the documents and encouraged to ask questions and provide design feedback. Then OT was asked to assemble the device with instructions on the paper without other support. They were required to think out loud and ask questions if they weren't sure about the process. We observed their behaviors and recorded the questions they asked in the workshop. At last, OT-EB and OT-SC evaluated the system package design and suggested improvement on the design.



Figure 20 OT-EB was assembling switch to wires while reading instructions



Figure 21 OT-SC used heat gun to connect the wires

Both the workshops were conducted at their working space and took around half an hour to complete. After reviewing the documentation for hand measurement, OT-EB wanted to make some wording changes to make it clearer for OTs to follow. Both OT-EB and OT-SC has no suggestions about the purchase part list. When they start assembling the device following the instructions, we found that they stop the process and looking for tools, such as heat gun or scissors. During the assembly process (see Figure 20 and Figure 21),

they both misinterpreted the switch wiring step. In other word, they didn't know how many wires for each switch.

During this participatory design process, both OTs were provided with a reference design, and they engaged in the design by providing the designer with design feedbacks and suggestions through describing the design in detail. Designer would confirm the design by sketching out the ideas and present the new design to the clinicians.

We modified the assembly manual (see APPENDIX D. SYSTEM PACKAGE DESIGN V2) based on their suggestions and sent the final documentation to OT-KC.

Since OT-KC was trying to print the parts using his own printer and failed (he failed to remove the supporting materials), we send the printed parts in the package along with the rest of the device components. The revised system package documents were sent to him via e-mail. After he evaluate the design, he thought the instructions were easy to follow to assemble the parts, and no further changes needed.

CHAPTER 5. FINDING AND DISCUSSION

5.1 Conclusion

OTs commented that the USAT-HS system is easy to use to design and build the device for clients. They all agreed that it is a promising field to take advantage of 3DP technology to create highly customizable, cheaper, available alternatives for their clients. They look forward to seeing more of this in the future work. They are not familiar with this 3d modeling and printing technology but very willing to explore more design opportunities, which is positive to this field of application.

“It’s a quick easy method to make your own switches using 3DP... because those pre-fabricated ones are not always customized... and children can use it, other users can use it. It has many potential applications”, OT-SC expressed the idea of leveraging this type of system to design some other ATs in the future.

“USAT-HS system is a step into the 3DP world”, OT-EB: “for certain individuals this is a good way to increase their access to the 3DP technology; this is an easy and inexpensive way to do it in clinics, which is very important to the clients (patients).”

As novice user, the OTs participated in this project had problem in interpreting design information from 3D CAD renderings since they were not familiar with product design process. It’s very important to present concept to them with physical artifact and face-to-face discussion. They are not familiar with design possibilities and would dare to communicate their direct thoughts, thus think out loud communication method is very useful to know what their thoughts on certain design concepts. Design efficiency could be

increased by letting OTs familiar with design process and the design scope. Detailed documentation of project related information would benefit the design process a lot.

OTs emphasized during the project that it's very important to make sure that the USAT cost is affordable and accessible. For commercial use, permanent license of Rhino 6 is \$995 (at the point of this project), and GH and Human UI are free plugins. The cost for 3D printed human-device interface (the carrying structure for switches) varies depending on the printer and material selection, and size of the artifact, thus it is hard to conduct cost analysis. A good estimation is that, for a hand length of 130 mm (a 6 years old hand length), it will cost around \$30 to print with FDM printing method. For a man's hand with length of 207 mm, it will cost around \$45 for 3DP. The rest of the switch control components, including straps (\$2), switches (\$1.5 for each), connectors and mono plug (\$5 for each set) will cost around \$10. It is reasonable to estimate that for each fabricated user specific hand-mounted switch control that designed using this USAT-HS system, it will cost around \$40 ~ \$55 without taking account of the software cost, which is considered acceptable by OTs.

Compared with current online downloadable assistive technology sharing community, e.g. example thingiverse.com, the USAT-HS system was co-designed and has been validated by OTs, and the ATs generated from this system are safe for end users to use. Moreover, GH has better modeling capability and is more designer-oriented than OpenSCAD, which is used for modeling the customized models on thingiverse.com. However, the customizer feature UI on thingiverse.com is easier to access than the USAT system UI created using GH and HUI. The former is web based and user can access the application if they have computer and internet connection, while the USAT was developed

in Rhino environment and user must have access to this commercial CAD modeling software. Additionally, thingiverse.com is a massive online community and user could share their design and communicate about design ideas globally, there are better chance to explore different AT design cases than doing it solely on local development environment like USAT system.

Compared with the AT adoption generating software Reprise, USAT has better clinical support from healthcare professionals to provide AT design and evaluation knowledge, while Reprise is focus more on the software capability. The versatile software developed by the computer scientists has a broader application in terms of designing ATs, since it is developed using scripts rather than modeling software which has design limitations (for both device model and UI design). Reprise also allow user with freedom to use the application independently, while in this study USAT-HS must rely on Rhino and GH.

5.2 Limitation

There are several limitations of the project. First, this project did not involve the end user of the hand mounted switch control design to participate during the design or evaluation phase, which might lose some practical advice. Secondly, the device design was limited by the trade-off between many pre-defined design constraints. It is desirable to reduce the uncertainty of the project and facilitate the design process, while it also limits the potential design outcome of the system. For example, the 3D printer selection was decided for user's convenience, but the user has limited options to print the parts. Finally, formal survey and interviews about the user prior experience of using 3D modeling and

3DP technologies might be needed to provide a baseline for the study to evaluate the new UI design effectiveness.

Other technical limitations of this project include limited investigation in other scripting-only tools, such as JavaScript or OpenSCAD. Those tools require high level of programming skills and the end results might be worth exploring. Moreover, although Rhino and its plugin works fine in this project, the intense manual labor needed to generate the actual model and UI still makes it hard to be generalized for the application in other similar projects. The system will become very slow when there is not enough computing power. More case studies need to be done to make sure the effectiveness of this method.

From an industrial design perspective, there could be more details for the hand mounted switch control design, such as adding food/water protection features for the living hinge finger gaps or conducting testing to validate the durability of the 3D printed parts. However, GH has limitations in terms of generating complex models. In this study, designer had to balance the functional requirements of device design and the technical requirement of the development of the model in GH. Although during the workshop, OT-EB and OT-SC completed the device assembly without breaking any parts, we found the switch mounting walls on the base 3D printed part (FDM, ABS) are very fragile and easy to break when mounting the switches in. Those walls still need to be reinforced. We designed some more switch mounting walls with different thickness and fillet features at the bottom to improve the durability and 1.5 mm wall thickness with fillet feature at the bottom works well. Those printed with Nylon powder are also much more durable and smooth than those printed by FDM (ABS).

5.3 Future Work

This project explored the potential for OTs to leverage the benefit of RP, assist them to take advantage of 3DP to facilitate the design and fabrication of ATs for their clients. Future work should explore other design cases, such as wheelchair mounted AT, splints and other commonly needed devices. End users should also be involved to ensure the design was end-user centered and meet all his/her specific needs. Additionally, there is design potential to collaborate designers, clinicians and developers to design and develop the USAT platform using web-based application or as a stand-alone software application to optimize the UI to allow for easier deployment of the system.

APPENDIX A. INITIAL DESIGN RENDERINGS

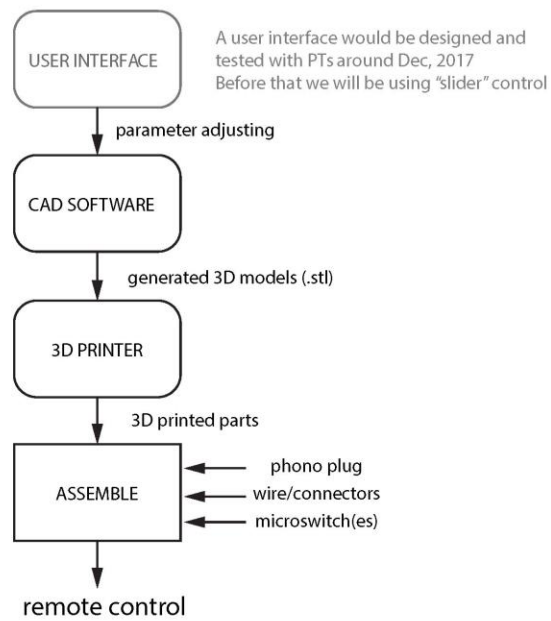
User Specific Assistive Technology Thesis Design
Xiuxiu Yuan | Master of Industrial Design
Georgia Institute of Technology

Objective:

to develop a system for physical therapists, to facilitate the design and delivery of hand-held, low-force switch controls for persons with disabilities.

Design and work flow chart

Information/action flow chart for PTs





This rendering shows the assembled control with strap and phono plug connector



Base Rendering



Shell Rendering

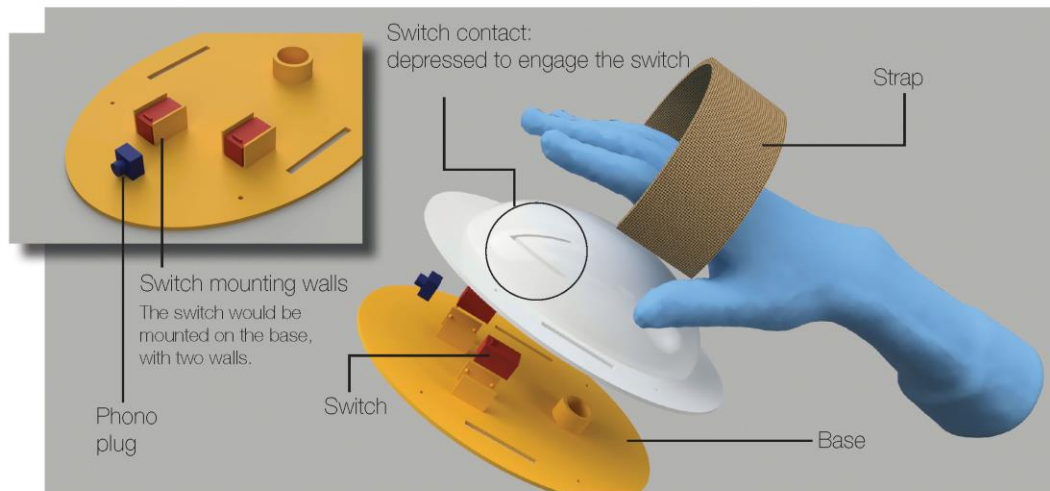
Initial Design Concept

The design idea is to start with a simple form (elipsoid) as the mounting piece for the switch. In the first design concept, I used mouse clicking mechanism and microswitch to realize the low-force clicking.

Base - the base would have detailed features to secure the switch(es)

Shell - the shell would have switch contacting piece(s) and some support features

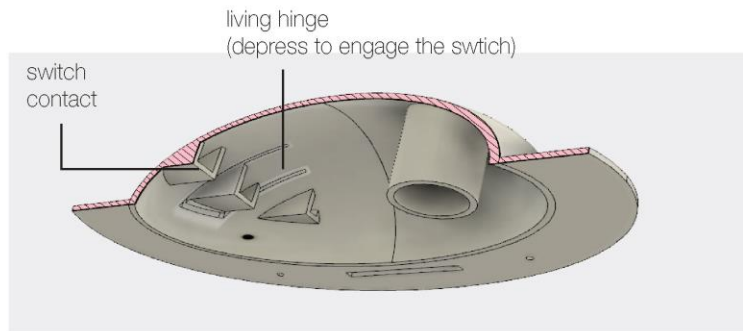
Base and shell: snap fit, velcro strap



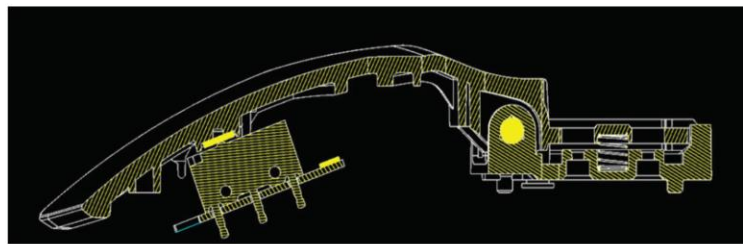
This rendering depicts two switches for the index finger and ring finger - the clinician will be able to select one or more switch actuations

Mouse Clicking Mechanism

mouse clicking mechanism and microswitch to realize the low-force clicking.



Section view of the hand mounting interface

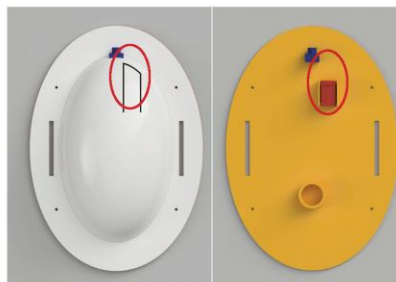


mouse clicking mechanism illustration

Choose the fingers

The user(clinicians) could choose whichever finger(except thumb) to trigger the switch, even multiple fingers.

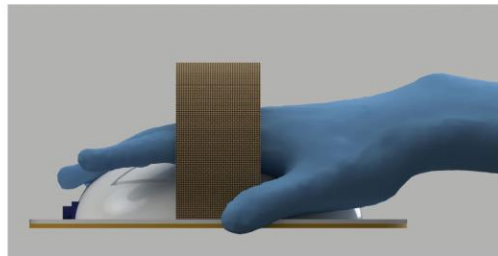
- the clinician will be able to select one or more switch actuations



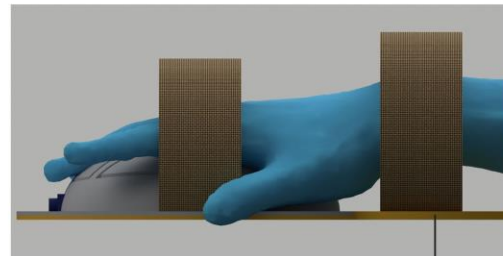
Right hand- ring finger



Right hand- index finger and ring finger



strap point: palm



strap point: palm and wrist

Extended base board

Strap Location(s)

In order to place secure the hand mounting interface to the user's hand, straps with vecros would be utilized. One option would be having the strap on the palm area, another option would be adding one more on the user's wrist. The base would have an extension if adding wrist strap. Please see the image for better illustration.

Final assembly

After printing out the base and shell, user could insert micro switch into the switch walls, connect the wires between switch and phono plug(ideally without using soldering), insert phono plug, snap the base and shell together. Finally, the 3D printed remote control mounting parts would be attached to patient's hands with commercial vecro band.



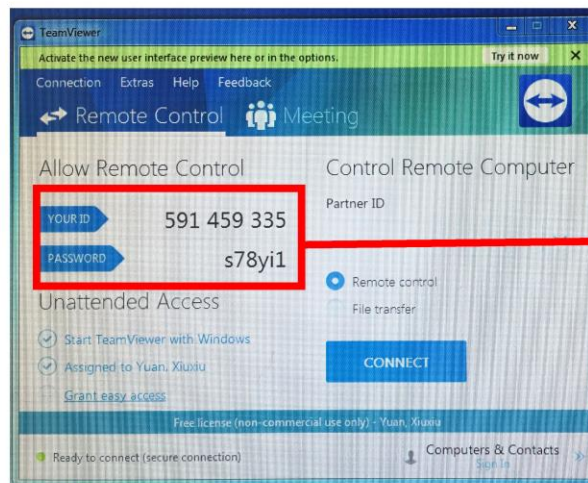
APPENDIX B. WORKSHOP USER MANUAL

Control REAR Lab Desktop Remotely via TeamViewer

User manual for USAT

Xiuxiu Yuan

Please download TeamViewer (free for non commercial use) using this link if you have not done so:
https://www.teamviewer.us/?utm_referrer=https%3A%2F%2Fwww.google.com%2F



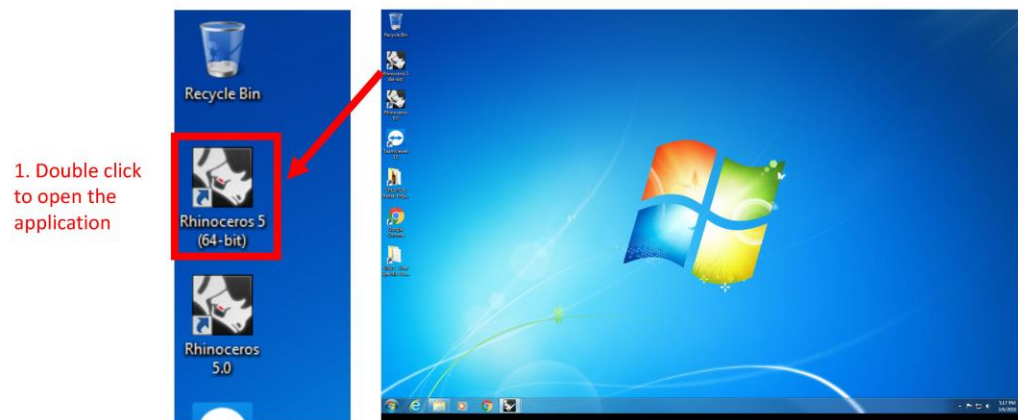
Please enter these two codes and connect your desktop to the REAR Lab desktop.

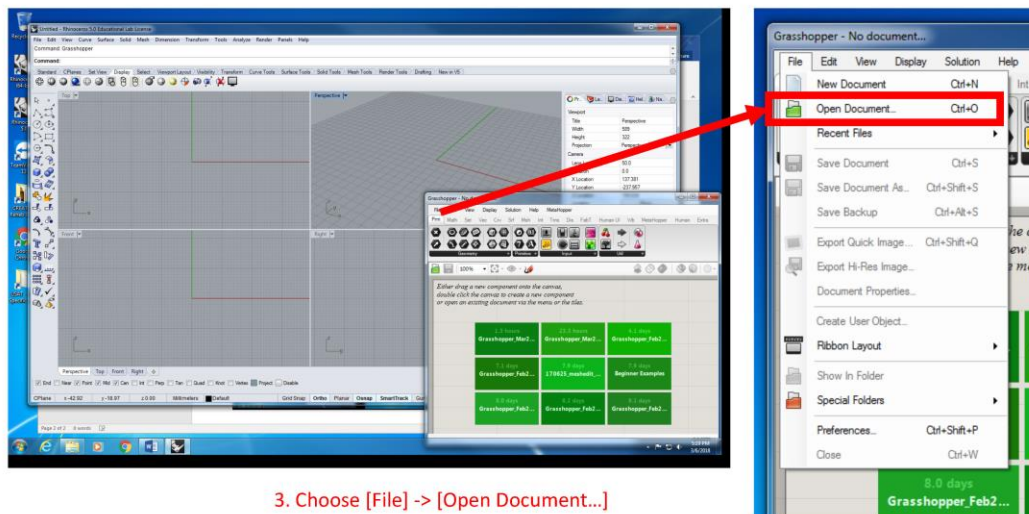
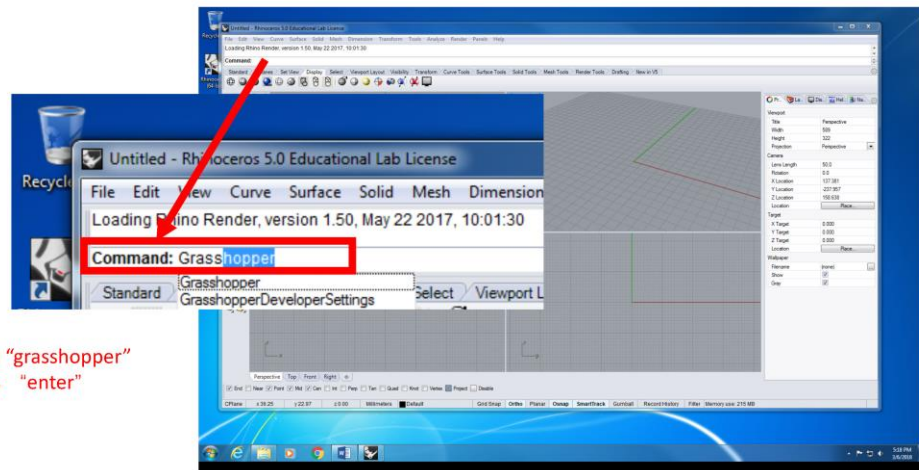
If connected, you should be able to see and control REAR Lab's desktop.

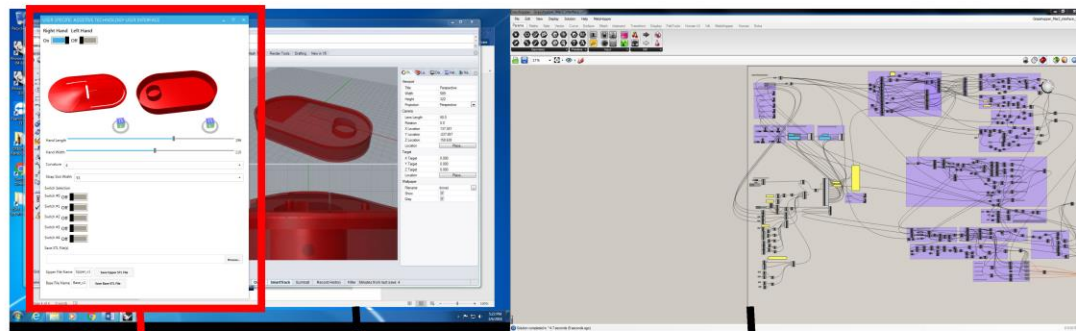
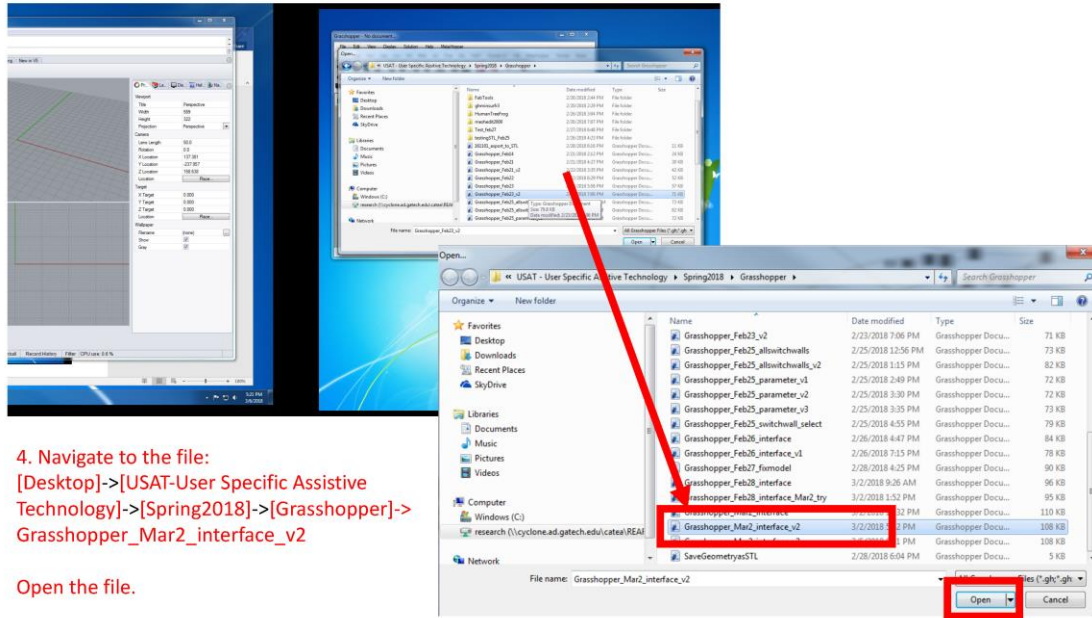
Open file with Grasshopper

User manual for USAT

Xiuxiu Yuan







5. Now you will see the interface for this project

This is Rhino, you don't need to interact with this, but you can use this as alternative model preview window

This is grasshopper interface, you don't need to interact with this for now.

User Interface/Interaction

User manual for USAT

Xiuxiu Yuan

NOTE: This system is VERY SLOW due to the model complexity. Please allow the system to load and it might take a while.

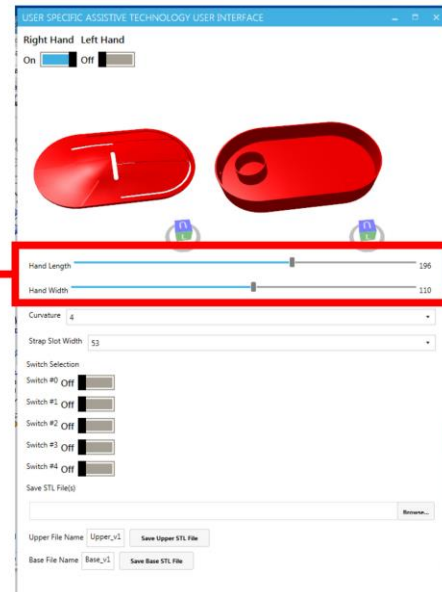
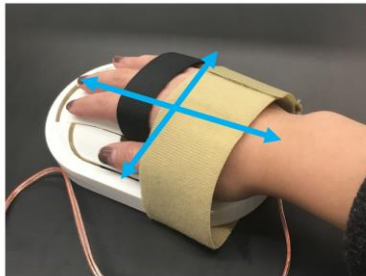
If the system is frozen, please go to Grasshopper menu bar, [solution] -> [recompute]. The system would refresh.

1. Choose left hand or right hand

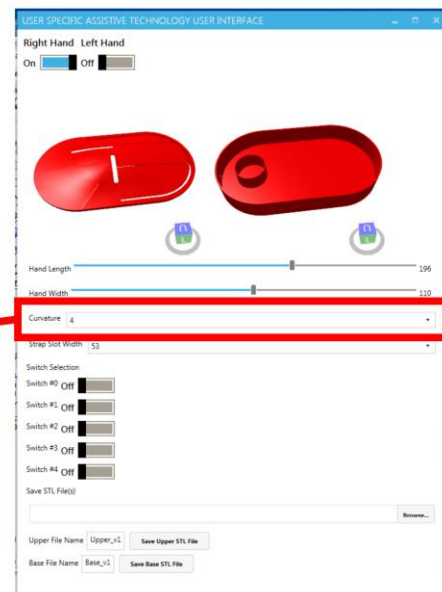
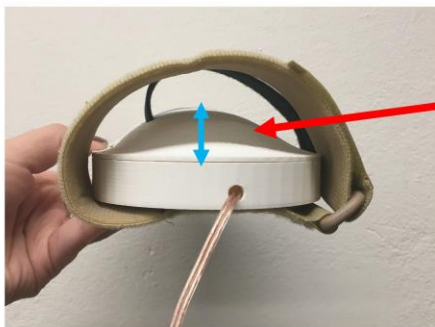
2. 3D CAD Preview, you can rotate and zoom in/out



3. Hand length & Hand Width
The maximum length of the user's hand in the final position(how you want the users' hand to be when they are interacting with this device)



4. Curvature Selection
The curvature of the hand mounting interface is set to 3 degrees: 4mm, 8mm and 12mm.



5. Strap Slot Width

The designer can select different strap width for the end user.

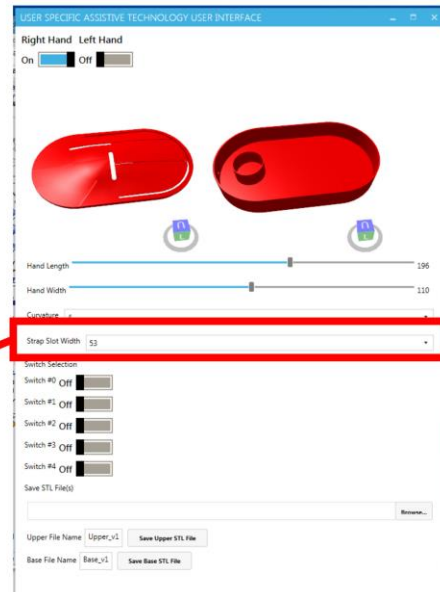
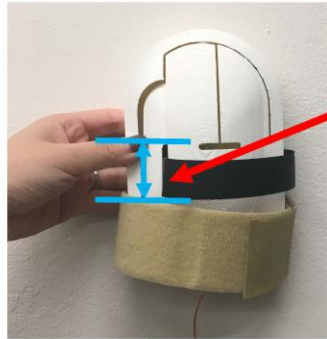
5/8 in = 18mm

3/4 in = 22 mm

1 in = 27 mm

1 1/2 in = 40 mm

2 = 53 mm



6. Switch Selection

#0- thumb

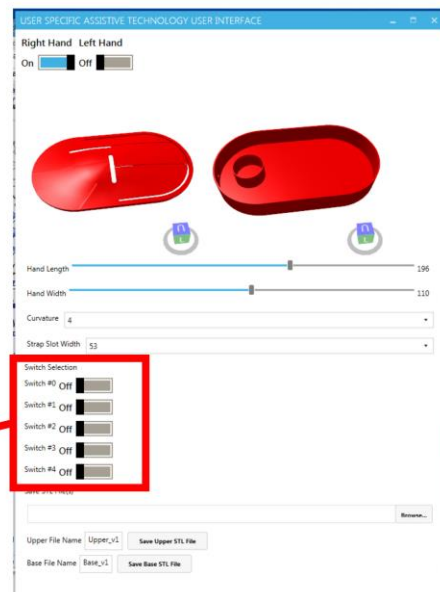
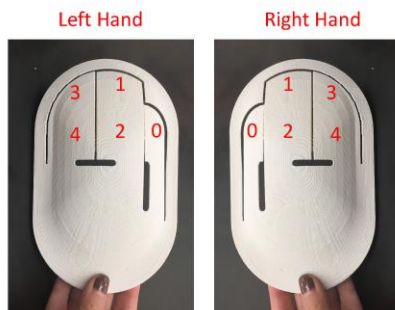
#1 light

#2 less light

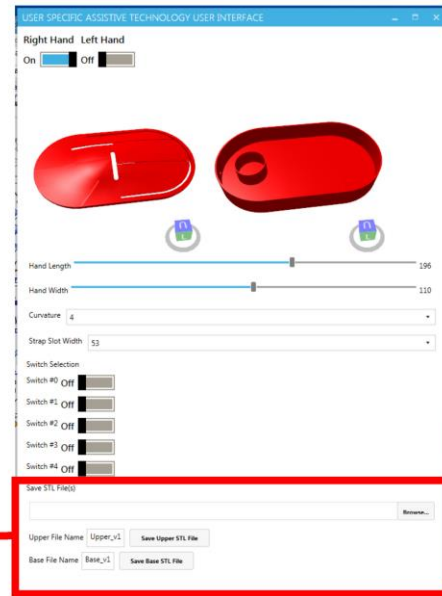
#3 light

#4 less light

The switches are designed to be very light, if you want to increase the force to activate them, you can use high force switch instead.

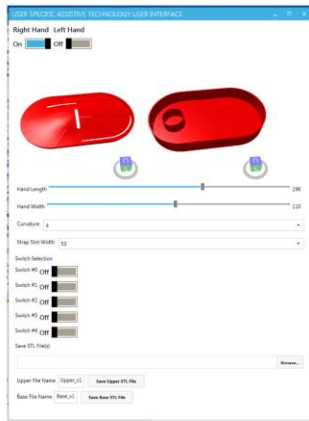


7. Save STL file ready to 3D print
- Choose save location
 - Name upper piece, save
 - Name base piece, save

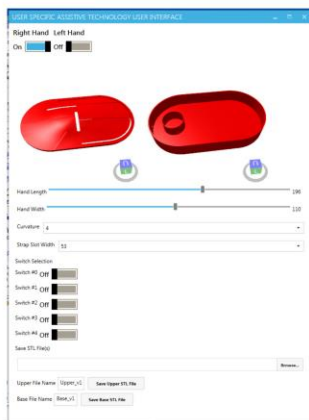
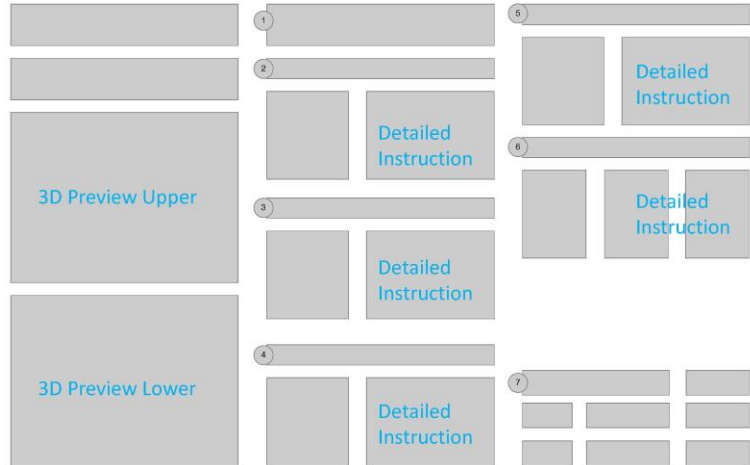


After you tried the interface design of the system, please review the following interface design alternatives.

Which one you think is better? Worse? Why?

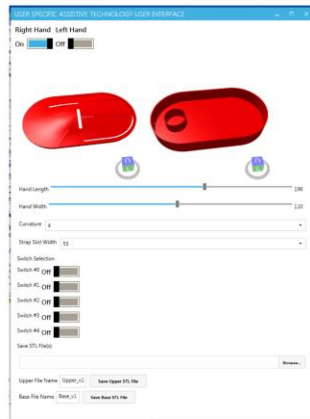


→
Option 1

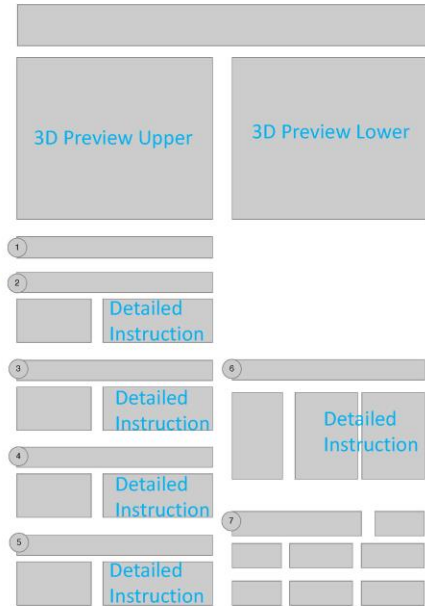


→
Option 2



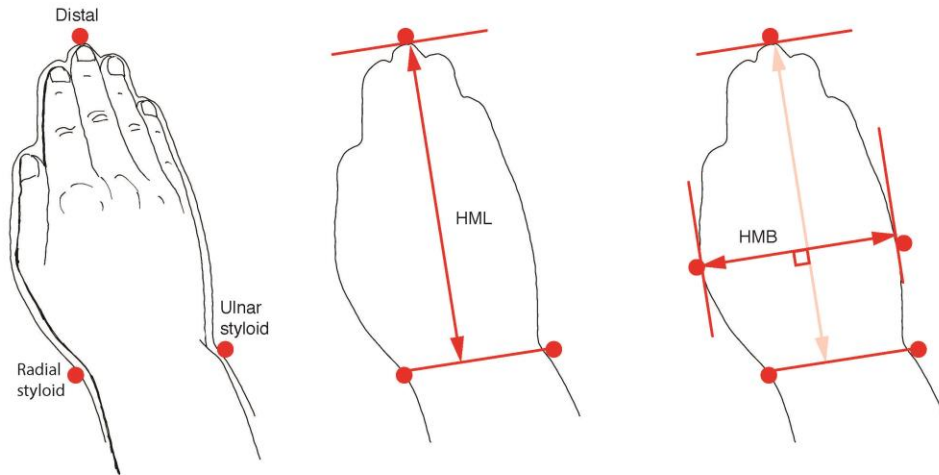


Option 3



APPENDIX C. SYSTEM PACKAGE DESIGN V1

Measure the hand for USAT



1. Place your hand as *how you want to use the device*, at a flat surface with all fingers closed.

Trace the hand and mark the wrist on both sides, and mark the distal point of the hand (usually at fingertip).

2. Measure the distance between the distal points to the wrist as shown: Hand Maximum Length (HML).

3. Mark the widest two points and measure the Hand Maximum Breadth (HMB) as shown.

Commercial Parts for Master Thesis Project: User Specific Assistive Technology

1. Switch (A)

Low force switch

Manufacturer: HONEYWELL

Manufacturer Part No: V7-3E17D8

Price: \$ 1.51/pc

<https://goo.gl/ydxK3y>



OR

User can choose other switches for various switch operating force.

2. Connector (B)

Spade connector with wire lead

6.3mm Crimp Terminal Female Spade Connector with 15cm 18AWG Wire, \$0.17/pc

<https://goo.gl/C27HvE>



OR

Without lead: user need to crimp the wire with this connector

Female Nylon Disconnect Spade Terminal, 0.25", \$0.12/pc
<https://goo.gl/bVEA3M>

3. Mono Plug (C)

Mono plug with wire lead

3.5mm 1/8" male mono plug

2 pack \$7.99(\$4.0/pc) <https://goo.gl/WZtpUM>



4. Part (D)

Solder Seal Heat Shrink Butt Connectors

Spec: Shrink Connectors: diameter 1.7 mm, cable cross-section 0.25-0.34 mm²(A.W.G:26-24).

50 pc \$12.99(\$0.26/pc) <https://goo.gl/31o7pA>

or: Diameter: 2.7 mm, cable cross-section 0.5-1.5 mm²(22-18AWG), Shrink ratio 2:1

50pc \$10.89(\$0.22/pc) <https://goo.gl/h7dQsc>



5. Palm Strap (E)

1": \$2.9/pc, 2": \$2.3/pc

<https://www.healthproductsforyou.com/p-rolyan-softstrap-self-adhesive-straps.html>



6. Wrist Strap (F)

Self-Adhesive D-Ring Cushion Strap with Velcro Hook and Loop

1"W x 12"L (2.5 x 30cm) \$2.9/pc

2"W x 12"L (5.1 x 30cm) \$3.5/pc

<https://www.healthproductsforyou.com/p-self-adhesive-d-ring-cushionstrap-with-velcro-hook-and-loop.html>



7. Hook Velcro (G)

Use the hook side to position the palm strap:

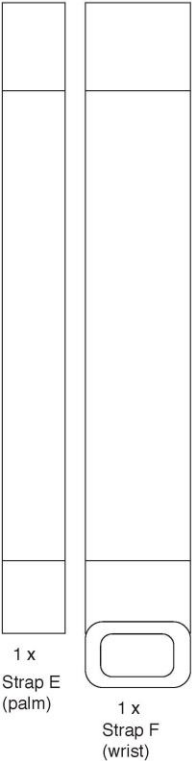
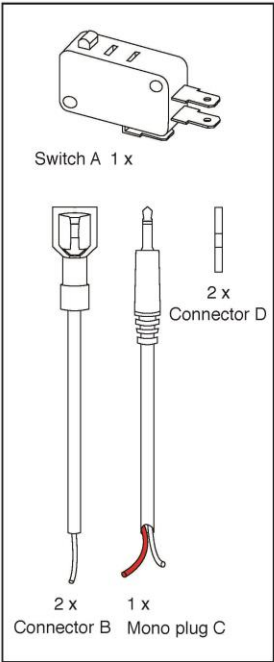
1" black self-adhesive hook strap: \$7.49/15 feet

<https://goo.gl/WJlVi4>

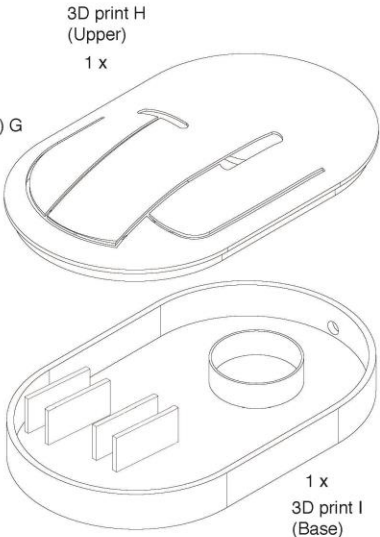


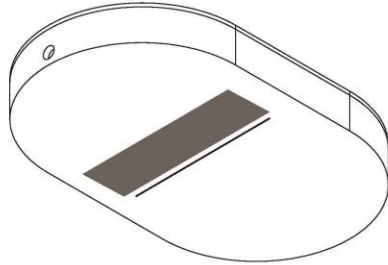
Parts for User Specific Assistive Technology

Multiply by the amount of the switch that is needed for the device

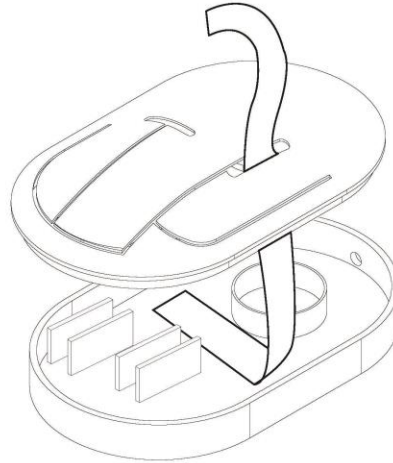


1 x Velcro (hook) G

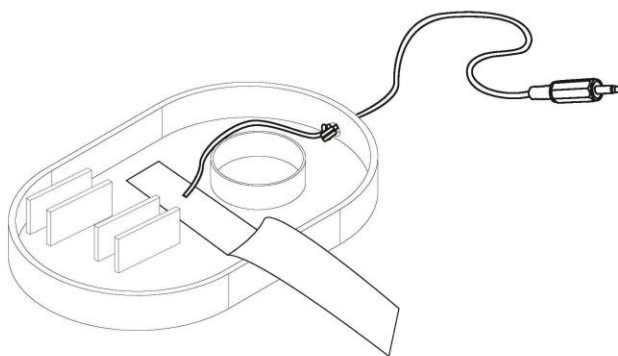




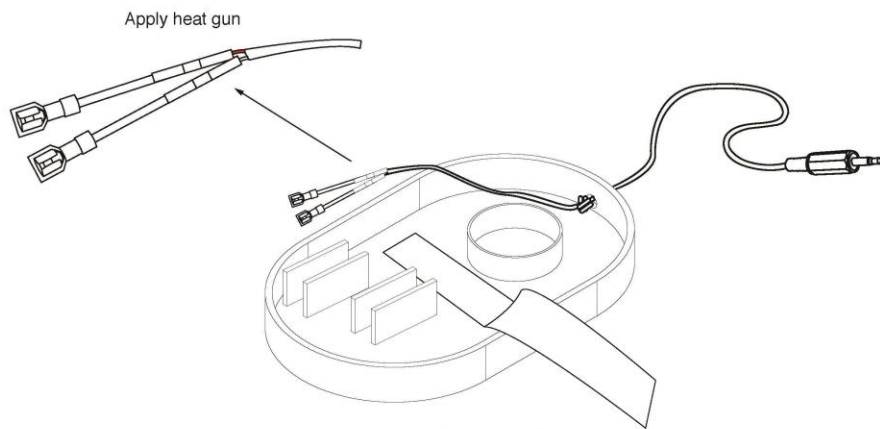
1. Apply the sticky side of the Velcro (hook) G to the bottom of the 3D print base I, close to the center and towards wire hole.



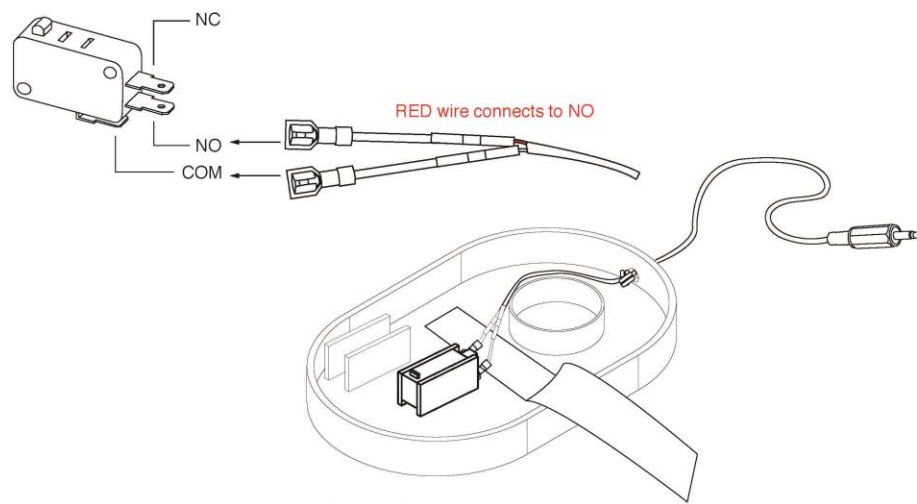
2. Apply the sticky side of the cushion strap (for palm) E to the bottom of the 3D print base (inner) I, close to the center and strap slot location.



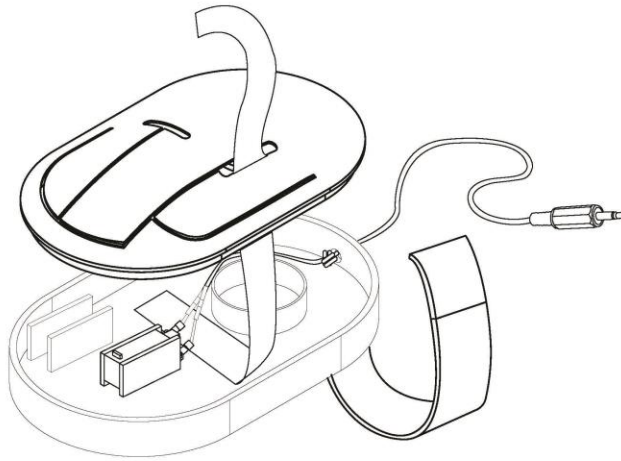
3. Run the wire of the mono plug C through the hole on the base I; and make a knot at desired length as a strain relief(as shown).



4. Connect the wires of mono plug C with connectors B via connector D using heat gun.



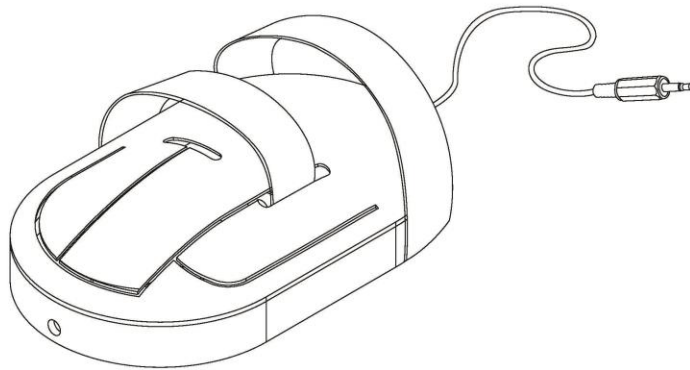
5. Connect Connector B to Switch A and snap the Switch A into the 3D print base I.



6. Repeat 3-5 when you have more than one switch.

7. Put the 3D print upper H on top and run the Strap E through the strap slot on H.
Add Strap F using the self adhesive side for wrist strap as shown, place at desired location.

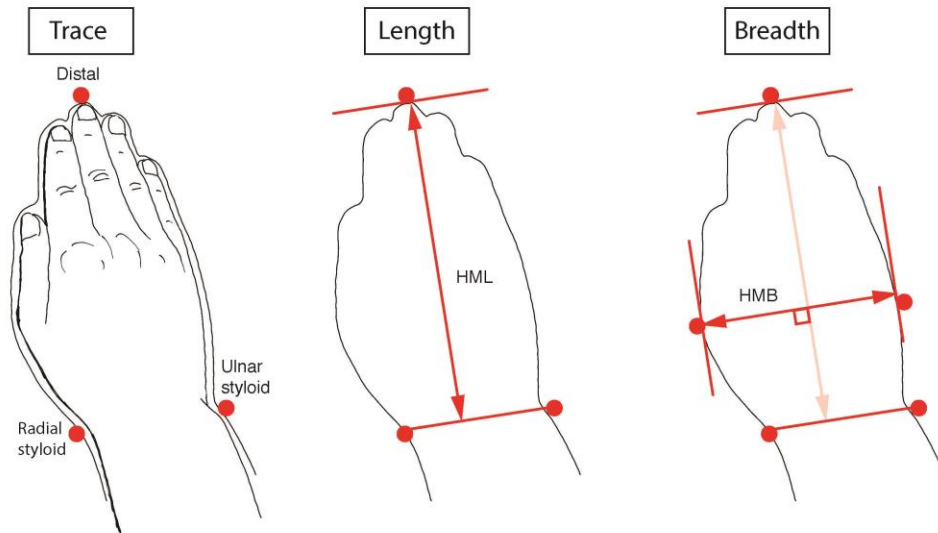
Congratulations! You've just created a highly customized assistive device!



Thank you for your participation.
Please let me know if you have any feedback or questions.

APPENDIX D. SYSTEM PACKAGE DESIGN V2

Measure the hand for Switch Interface



1. Place your hand as the position *you want to use the device*, at a flat surface with all fingers closed.

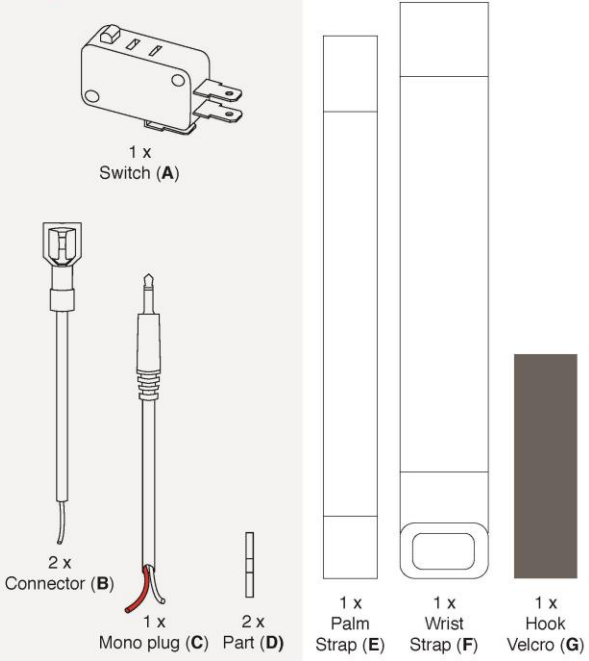
Trace the hand and mark the wrist on both sides, and mark the distal point of the hand (usually at fingertip).

2. Measure the distance between the distal points to the wrist as shown: Hand Maximum Length (HML).

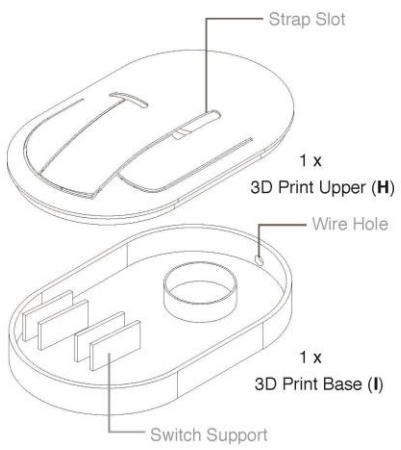
3. Mark the widest two points and measure the Hand Maximum Breadth (HMB) as shown.

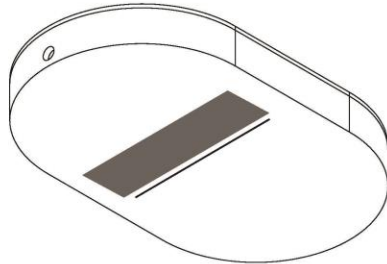
USAT- Remote Switch Control Assembly Manual

Each switch has:
2 B Connectors, 1 Mono Plug C,
and 2 Part Ds.

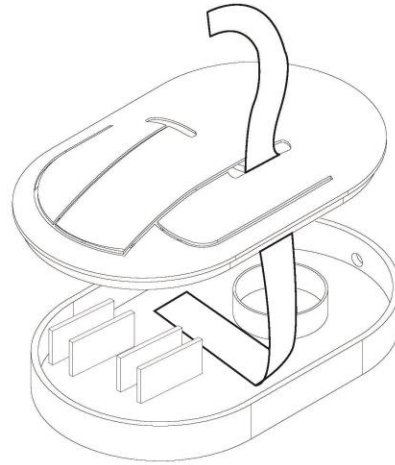


- Tools for assembly:
- (1) Scissors
 - (2) Wire Stripper
 - (3) Heat Gun
 - (4) Ruler

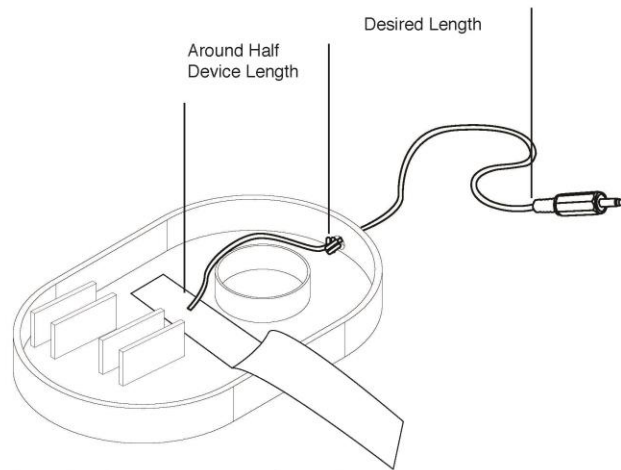




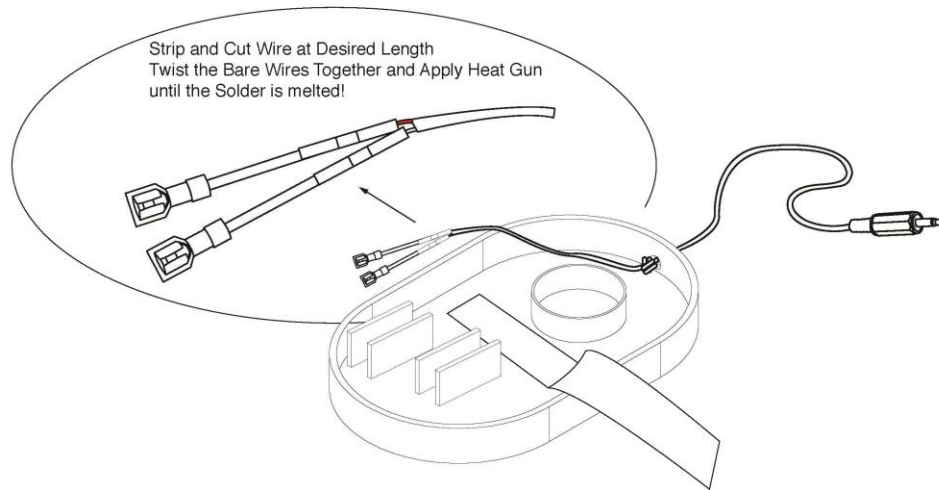
1. Apply the sticky side of the Velcro (hook) G to the bottom of the 3D print base I, close to the center and towards wire hole.



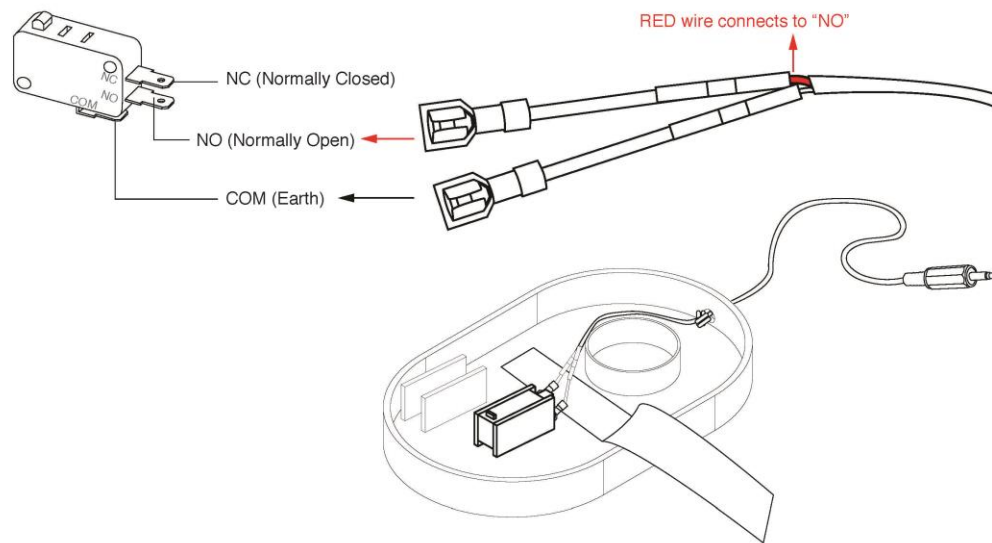
2. Apply the sticky side of the cushion strap (for palm) E to the bottom of the 3D print base (inner) I, close to the center and strap slot location.

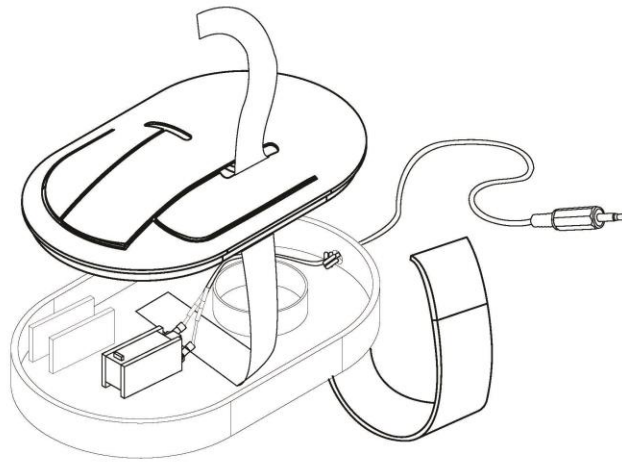


3. Run the wire of the mono plug C through the hole on the base I; and make a knot at desired length as a strain relief(as shown).



4. Connect the wires of mono plug C with connectors B via connector D using heat gun.



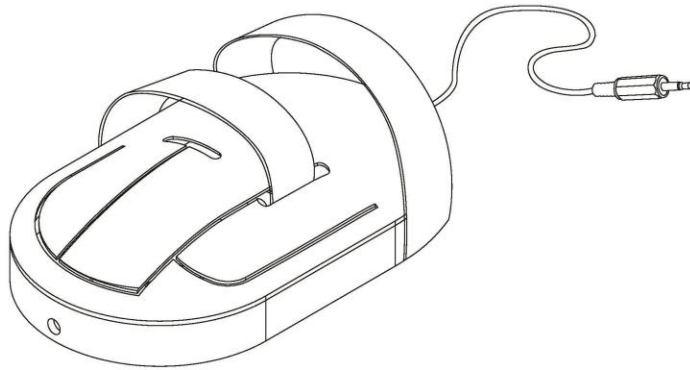


6. Repeat 3-5 when you have more than one switch.

7. Put the 3D print upper H on top and run the Strap E through the strap slot on H.

Add Strap F using the self adhesive side for wrist strap as shown, place at desired location.

Congratulations! You've just created a highly customized assistive device!



Thank you for your participation.
Please let me know if you have any feedback or questions.

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